DOCUMENT RESUME

ED 325 675 CE 056 256

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TITLE	Semiconductor Devices and Applications. Electronics Module 5. Instructor's Guide.
INSTITUTION	Missouri Univ., Columbia. Instructional Materials Lab.
SPONS AGENCY	Missouri State Dept. of Elementary and Secondary Education, Jefferson City. Div. of Vocational and Adult Education.
PUB DATE	90
NOTE	351p.; For related documents, see ED 315 659-662 and CE 056 257-261.
AVAILABLE FROM	Instructional Materials Laboratory, University of Missouri, 2316 Industrial Drive, Columbia, MO 65202 (Order No. 70-5005-I: $15.00).
PUB TYPE	Guides - Classroom Use - Guides (For Teachers) (052)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	Behavioral Objectives; Competency Based Education; *Electronics; *Industrial Arts; Learning Activities; Learning Modules; *Microelectronics; Postsecondary Education; Secondary Education; *Semiconductor Devices; State Curriculum Guides; *Trade and Industrial Education
IDENTIFIERS	Missouri

ABSTRACT

This module is the fifth of 10 modules in the competency-based electronics series. Introductory materials include a listing of competencies addressed in the module, a parts/equipment list, and a cross-reference table of instructional materials. Sixteen instructional units cover: semiconductor materials; diodes; diode applications and rectification; unregulated power supplies; power-supply filters; special diodes; zener-regulated power supply; bipolar junction transistor (BJT); multistage amplifiers; linear integrated circuits; thyristors; three-terminal regulator; oscillators; servicing BJT amplifiers; servicing field-effect transistor (FET) amplifiers; and servicing op-amp circuits. Each unit includes some or all of the following components: performance objectives; information sheets; transparency masters; handouts; assignment sheets; job sheets; and unit test with answer key. Special instructions are included in the notes to the instructor section near the beginning of each unit. (YLB)

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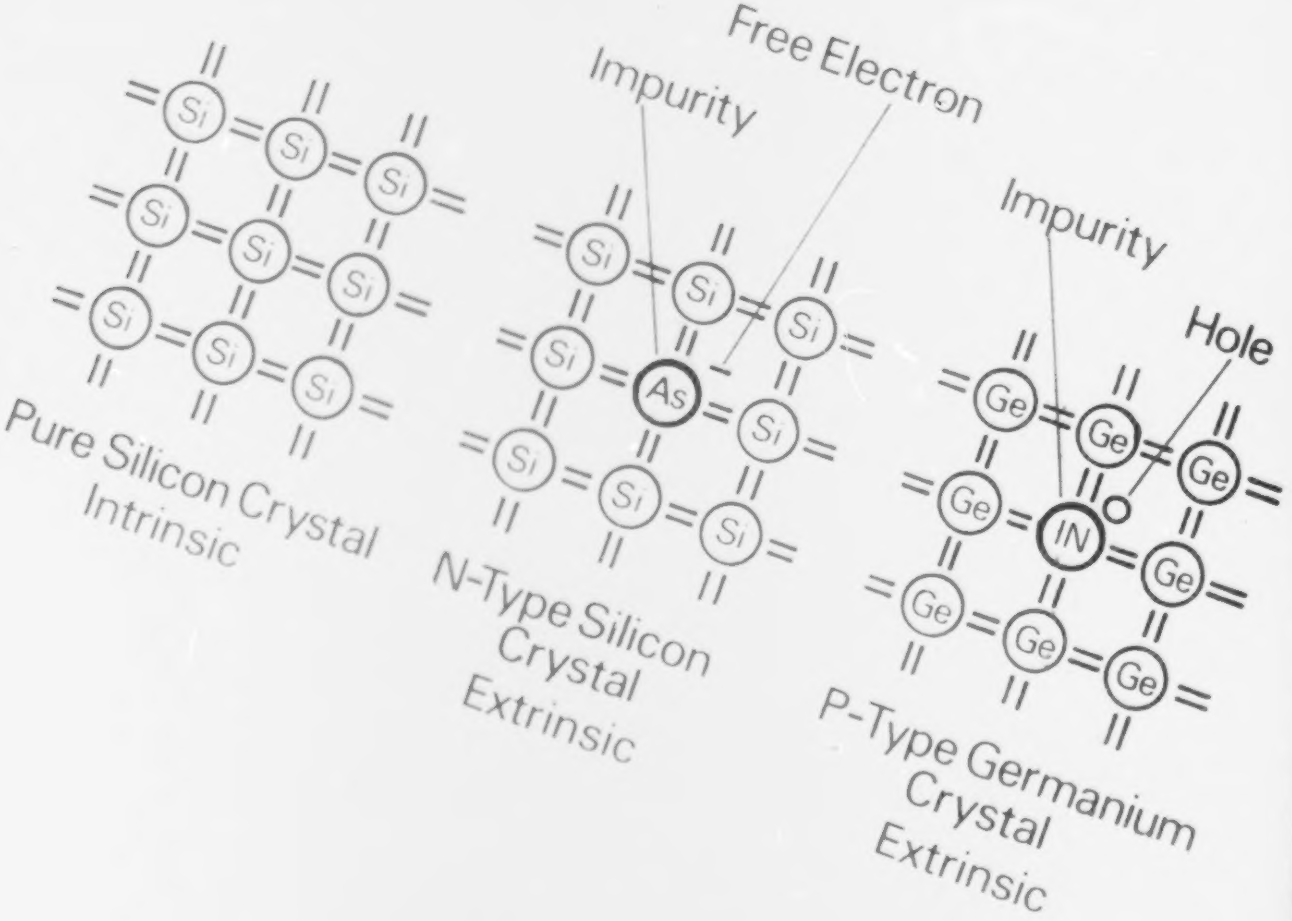
ELECTRONICS
Module

5

70-5005-I
Instructor's Guide

SEMICONDUCTOR DEVICES AND APPLICATIONS


Si
Pure Silicon Crystal
Intrinsic
Impurity
Free Electron
As
N-Type Silicon
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Modules in this IML Electronics series

1: *Electronic Safety* by Bill Tharp
2: *Fundamentals of Electronics* by Jim Everett
3: *Digital Logic Application* by Ed Carter and Mark Murphy
4: *Circuit Construction Techniques* by Don Slack
5: *Semiconductor Devices and Applications* by John Chappell, Bill Franken and Mark Murphy
6: *Receivers and Transmitters* by Jim Everett
7: *Testing and Troubleshooting* by Don Slack
8: *Microprocessor and Computer Systems* by Don Slack
9: *Optical Electronics* by Bill Franken
10: *Electromechanical Devices and Controllers* by Ed Carter

The activity which is the subject of this report was supported in whole or in part by funds from the Department of Elementary and Secondary Education, Division of Vocational and Adult Education. However, the opinions expressed herein do not necessarily reflect the position or policies of the Missouri Department of Elementary and Secondary Education or the Division of Vocational and Adult Education, and no official endorsement should be inferred.

ELECTRONICS

Module 5: Semiconductor Devices and Applications

by

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1990

Instructor's Guide
Catalog No. 70-5005-I

FOREWORD

Once again, we are indebted to the teachers and administrators who provide their time, efforts and professionalism to develop curriculum for trade, technical and industrial education programs. This electronics guide is an outstanding example of what can be accomplished when the right people with the right attitude get together. Committee members worked hard over several years' time in advisory, writing, technical consultation and field-test capacities.

This guide is designed to be totally integrated with the Vocational Instructional Management System. It is hoped that all guides produced under our supervision will help classroom teachers manage instruction. A curriculum guide is more than a resource--it is an integral part of the management system. Rather than impeding instruction, it should guide and facilitate instruction.

This guide's format has been set up for competency-based teaching and testing. Unit tests evaluate specific competencies and can be used with the Vocational Administrative Management System (VAMS). Information sheets, transparency masters, job sheets, assignment sheets and test items are keyed to specific competencies. A cross-reference table has been included to quickly identify parts of the curriculum that relate to specific competencies. The material has also been packaged for students.

Although this guide may be a new format for some teachers, we are confident that, when used as designed, time spent by teachers and students will become more productive. Any future electronics curriculum modifications will begin with this guide. The electronics field is undergoing constant and considerable change. We will annually evaluate the need to update this guide on a module-by-module basis. Your suggestions regarding areas for improvement are both encouraged and appreciated.

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Department of Elementary and Secondary Education

Charles "Chuck" Waibel, director
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ACKNOWLEDGMENTS

This electronics guide represents a continuing commitment to Missouri's Vocational Instructional Management System (VIMS). The guide has been keyed to the electronics competency profile developed by industry and education professionals in the state.

When searching for current electronics materials to adopt or utilize in the guide's development, comparable materials were found from the Mid-America Vocational Curriculum Consortium (MAVCC), of which Missouri is a member. MAVCC materials, therefore, have been relied upon as a resource for this guide. A debt of thanks is owed to the entire MAVCC organization for the research and development of these electronics materials.

Special appreciation is given to the writers (Ed Carter, John Chappell, Jim Everett, Bill Franken, Mark Murphy, Don Slack and Bill Tharp) for their self-motivation, reliability and technical expertise. IML employees Crystal Dietiker and Donna Curtis contributed greatly to the guide's production.

These industry representatives and educators contributed to the guide as members of the advisory committee.

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Don Slack, Graff Area Vocational Center, Springfield
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Mark Ward, Lewis & Clark Technical School, St. Charles

Support and contributions of IML staff members were instrumental to this module's development.

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Amon Herd, associate director
Phyllis Miller and Dan Stapleton, assistant directors
Sharon Dyer, graphic designer
Hsiu-Nien (Shelley) Chen, student assistant - technical
Donna Curtis and Lori Holliday, word processors
Mary Beth Ramsey, student assistant - clerical

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COMPETENCIES ADDRESSED IN THIS MODULE

B. Fundamentals of Electronics

2. Describe the basic physics of semiconductor materials
14. Identify and test inductors
18. Calculate RC time constant circuits
19. Describe and identify filter networks
20. Test and evaluate filter performance

C. AC Power Supply

1. Describe types of transformers
2. Determine transformer requirements
3. Determine rectifier (diode) specifications for specific installations
4. Select components for complete power supply
5. Identify and describe use of series regulators
6. Identify and describe use of shunt regulators
7. Identify and describe use of switching regulators
8. Install power supply components
9. Test power supply and correct defects

D. Semiconductor Devices

1. Identify schematic design symbols for semiconductor devices
2. Describe the operation of junction diodes
3 Describe the operation of bipolar transistors
4. Construct circuits using bipolar transistors

5. Describe the basic operation of a JFET
6. Describe the basic operation of a MOSFET
7. Describe the basic operation of a UJT
8. Describe the basic operation of a PUT
9. Describe the basic operation of a DIAC
10. Describe the basic operation of a SCR
11. Describe the basic operation of a TRIAC
12. Describe the basic operation of a VDR
13. Test diodes
14. Test transistors
15. Test thyristors
16. Select transistors for specific purposes using specification sheets and substitution guides
17. Demonstrate the proper replacement techniques for semiconductor devices

E. Amplifiers

1. Describe the operation of a bipolar amplifier
2. Describe the operation of a FET amplifier
3. Describe the operation of an operational amplifier
4. Test and repair bipolar amplifier
5. Test and repair FET amplifier
6. Test and repair operational amplifier
7. Describe amplifier coupling techniques
8. Measure frequency response of amplifiers

F. Frequency Generation

1. Describe the basic operation of oscillators
2. Describe the basic operation of a crystal oscillator
4. Describe operation of waveform generators
5. Test and repair oscillators
7. Test and repair waveform generators

H. Test Equipment

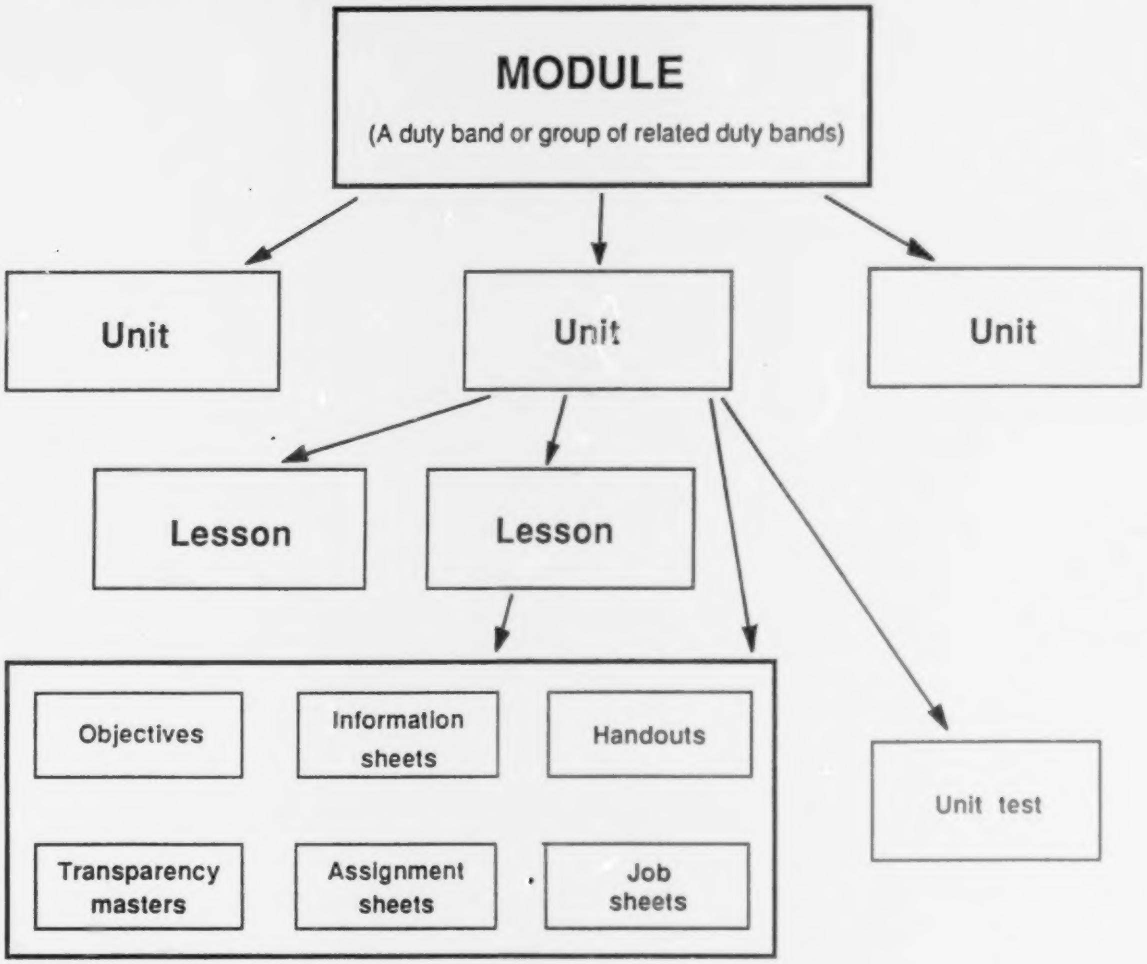
4. Describe the operation and demonstrate the use of a frequency counter

HOW TO USE THIS PUBLICATION

GUIDE COMPONENTS

Units of instruction

This Electronics guide contains ten modules of instruction. Within each module are instructional units including some or all of the following components: performance objectives, information sheets, transparency masters, handouts, assignment sheets, job sheets and a unit test. Special instructions on audiovisuals, supplies, etc. are included in the Notes to the Instructor section near the beginning of each unit.


MODULE
(A duty band or group of related duty bands)
Unit
Unit
Unit
Lesson
Lesson
Objectives
Information sheets
Handouts
Transparency masters
Assignment sheets
Job sheets
Unit test

Competency profile

On the Missouri competency profile, tasks are divided into general subject areas, or duty bands, which are identified by a capital letter. Under each duty band are related tasks (competencies), which are identified by an Arabic numeral. To evaluate the student on performance of the competencies, a 3-2-1-N grading system is used, where:

3 = **Mastery** - can work independently with no supervision
2 = **Requires supervision** - can perform job completely with limited supervision
1 = **Not mastered** - requires instruction and close supervision
N = **No exposure** - no experience or knowledge in this area

Cross-reference table (color-coded white)

Once the numbering system is understood, this table quickly reveals how the instructional components of the module relate to Missouri competencies. On the competency profile, tasks are divided into general subject areas, or duty bands, which are identified by a capital letter. Under each duty band are related tasks (competencies), which are identified by an Arabic numeral.

On the cross-reference table, unit numbers are represented by Roman numerals (I, II, III, etc.). Lessons within a unit are shown with Arabic numerals. Therefore, the first objective in Lesson 1 is numbered 1.1, the second is 1.2, and so on. Other components of the module (transparencies, handouts, assignment sheets and job sheets) also use this numbering system. By looking at the cross-reference table, the instructor can quickly determine what test questions or job sheets a student needs to receive an evaluation on a particular competency.

Objectives (color-coded white)

Each unit is based on performance objectives which state the measurable unit and specific behavioral or performance objectives that students are expected to achieve. Since the objectives of the unit provide direction for the teaching-learning process, it is important for the teacher and students to have a common understanding of the objectives' intent. Teachers should feel free to add/adapt objectives which will fit the material to student and community needs. Supporting material will, of course, need to be added for any new objectives.

Table of contents, references, notes to the instructor (color-coded pink)

These pages have been coded pink for instructor use only. The reference section lists materials used as sources in developing the material. Special instructions on audiovisuals, supplies, etc. are included in the Notes to the Instructor section.

Information sheets (green)

Presented in outline form for clarity, these pages provide content essential for meeting the cognitive (knowledge) objectives in the unit. Students should study the information sheets before class discussion or completion of assignment sheets. **CAUTION** statements indicate possible equipment damage, while **WARNING** statements recommend procedures to avoid bodily injury. Handouts and transparency masters have been keyed in the information sheets for instructional use.

Transparency masters (white)

Transparencies provide information by visually reinforcing or clarifying ideas presented in the information sheets. They are effective when identification is necessary and direct the class's attention to the topic of discussion. Transparencies should be left on the screen only when topics shown are under discussion, however.

Handouts (white)

Whenever more detailed information than can be presented in a transparency is needed, a handout is used. Handouts give the students additional information that can be kept with their class notes or student references.

Assignment sheets (tan)

Assignment sheets furnish paper-and-pencil practice to develop the knowledge necessary as a prerequisite to skill development. They can be given to students for class completion or used as homework assignments. Answer sheets (color-coded pink) can be used by the student or instructor to check progress.

Job sheets (blue)

These evaluation instruments are provided for two purposes: to outline steps of procedure and to check student performance mastery. Job sheets begin with a list of tools and materials needed for the activity. Job sheets furnish potential employers with a picture of skills being taught and performance which might be reasonably expected from a vocational student. The spaces to the right of the page on a job sheet assist the instructor in evaluating a student on a particular activity. This 3-2-1-N grading system is the same as the one used on the competency profile.

Unit test (yellow)

Competency-based tests are designed to help eliminate subjective testing and to improve student evaluation and accountability. Specific competencies and test questions are linked on the answer key. These unit tests have been written to be used with computerized VAMS (Vocational Administrative Management System), utilizing Scantron sheets for computer-recording of test answers.

The unit test may be eliminated if the competency was thoroughly evaluated by job sheets. However, an emphasis should be placed on cognitive as well as performance skills. If the objective or competency will be evaluated by a job sheet, it is often necessary to determine by a written test whether the student understands enough of the material to perform the job sheet.

SUGGESTED ACTIVITIES

The following list of suggested activities may be helpful, especially to the beginning instructor.

1. Provide students with objective sheet and information sheets.
2. Discuss unit and specific objectives.
3. Discuss information sheets, assignment sheets and/or job sheets, lesson-by-lesson.
4. Have students do assignment sheet(s) to satisfactory levels.
5. Give students unit test.
6. After successful completion of the test, have students do job sheet(s).

Students should perform the following activities.

1. Read objective sheet.
2. Study information sheets.
3. Do assignment sheet(s).
4. Take unit test.
5. Do job sheets.

PACKAGING

This Electronics guide has been packaged with the entire class in mind. For the teacher, a complete instructor's guide contains all ten modules. In the student reference, selected portions have been reproduced for student use (objectives page, information sheets, handouts). Student work sheets (assignment sheets, job sheets, unit tests) have been packaged together for student distribution as the instructor deems necessary.

In the student reference, page numbers do not run consecutively because some pages have been removed that appear only in the instructor's guide.

PARTS/EQUIPMENT LIST

Ammeters (0-50mA range)
Audio signal generator
Audio generator
Audio oscillator
Breadboard
Breadboard or proto-board
Capacitors: C_1 = 47μF, C_2 = 10μF, C_3 and C_4 = 4.7μF
Capacitors: two 0.22μF, 0.1μF, 0.02μF
Capacitors: 1μF, 15 V; 220μF, 15 V
Capacitors: .01μF, 16V (2); .1μF, 16V (2)
Capacitors: 0.1μF (2)
Capacitors: 1μF, 25 volts (4)
Capacitor, 10μF
Capacitors, 20μF, 450V (2)
Capacitor, 20μF, 25W V_{DC} or greater (3)
Capacitors: 25μF, 25 V; 100μF, 25 V
Capacitors: 680μF, 47μF, .01μF
1mHz crystal
Diode, IN4001 or similar type
Diodes, one or more
Electrical socket
Frequency counter, 21mHz
Function generator
General-purpose cross-reference manual
Graph paper
Hook-up wire
100W light bulb (or 100Ω, 100W resistor)
12-volt bayonet or other low-wattage lamp
12V lamp
Old printed circuit board (preferably double-sided with several semiconductors)
Resistors, 1/2W: 1KΩ, (2); 10KΩ (2); 22KΩ (2); 33KΩ (2); 100KΩ (2); 10KΩ adjustable
Resistors: 200K, 33K, 10K, 4.7K, 1KΩ, 1/2 watt
Resistors (two each): 470K, 1/4 watt; 47K, 1/4 watt; 2.2K, 1/4 watt
Resistors: 470K, 1/4 watt (2); 47K, 1/4 watt (2); 2.2K, 1/4 watt (1)
Resistors: 220Ω, 1/2 W; 2.2KΩ, 1/2 W; 10KΩ, 1/2 W; 22K, 1/2 W; 100K, 1/2 W
Resistors: One each of 1MΩ, 47KΩ, 1KΩ, 10KΩ and 1KΩ potentiometer (use 1/2 watt resistor)
Resistors: R_1 = 1K, R_2 = 2.2K, R_3 = 30K, R_4 = 120K, R_5 = 200, R_6 and R_{10} = 390, R_7 = 33K, R_8 = 116K, R_9 = 150
Resistors: One each of 47KΩ, 1KΩ and 1MΩ (use 1/2 watt resistor)
Resistors: One each of 1KΩ, 47KΩ and 1MΩ (use 1/2 watt resistor)
Resistor, 1KΩ, .5W (2)
Resistor, 1KΩ, 1/2 watt
Resistor, 10KΩ, 1W
Resistor, 10KΩ, 0.5W
Resistors: 10KΩ, .5W; 1KΩ, .5W
Resistor, 10K, .5W
Resistors: 27Ω, 100Ω, 1/2 W (2); 47Ω, 1.2KΩ, 10KΩ, 1/2 W (2)
Resistors: 3.3KΩ (7), 6.8KΩ (2)
Resistor, 62Ω, 1 watt
Resistors: 150Ω, 10KΩ, two 560Ω, 1KΩ, 470Ω, 330Ω
Resistors: 150Ω, 22KΩ
Resistors: 150Ω, 1/2 watt; 10KΩ, 1/2 watt
Resistor, 270Ω
Resistors: 470K, 1/4 watt; 47K, 1/4 watt (3); 2.2K, 1/4 watt
Resistors: 560Ω, 1W; 470Ω, 1W
Resistor, 560Ω, 1/2W
Resistor, 6800Ω, 1/2W
741 operational amplifiers (2)
LM339A op amp
LM741 op amp
LM340-5 regulator (3)
Loudspeaker, 8Ω
Microammeter (or multimeter)
Milliammeters (or multimeter) (2)
Multimeter
NPN transistor
Ohmmeter
Ohmmeter
Op amp, type LM741 or equivalent (4)
Dual-trace oscilloscope
Oscilloscope
Oscilloscope, frequency response to 20mHz
Potentiometer, 100KΩ, 1/2 watt
Potentiometer, 2.5KΩ
Potentiometer, 250KΩ
Potentiometer, 2.5KΩ, 1/2W
Potentiometers: 50Ω, 1W and 750 1W
Potentiometers: one 10KΩ and one 1KΩ (use 1 watt potentiometer)
DC power supply, +15 volt, or dual tracking DC supply
DC power supplies, two at 15V and .25A
DC power supply or DC source (battery), 12-24 volts with test leads
DC power supply, adjustable to 18 volts and 1.5 amps
DC power supply, +15V, or dual tracking DC supply
DC power supply (0-10 volts)
DC power supply to 18V
DC supply to 18V at 1.5A
Dual-polarity power supply (variable)
Power supply, variable low-voltage
Power supply, +15 volt, or dual tracking DC supply
Power supply, 0-$20V_{DC}$
Power supply, low-voltage (2)

Power supply, 15V
Power supply, 12VDC
Proto-board or equipment to connect an integrated circuit
Prototype board
Filament transformer, low-power (120V primary, 6-24V secondary)
Filament transformer, low-power ([illegible] primary)
Multiple-winding transformer wit[illegible]m, 60 Hz, 120- to 240-volt primar[illegible]p-down secondaries, wire leads attached
Power transformer (110V)
Transformer, low-power (120V primary, 6-24V secondary)
Transformer, 12V
Transformer, general purpose 115-120V_{AC}
Transformer, low-power (120V primary)
SCR (any general-purpose SCR, such as 2N5064 or 2N4444)
Semiconductors: TRIAC 2302B, DIAC TI43A
Signal generator to 1mHz
Signal generator
Silicon diodes, 1N4004 or equivalent (16)
Sine-wave generator
Substitution guide
Tank circuit, 1mHz adjustable
Transistor assortment (both signal and power types)
PNP transistor
Transistor tester (if available)
Transistors: 2N2222, 2N2907
Transistors: 2N2222, 2N3055 (1 each)
Power supply: 115V_{AC} isolated supply
DC power supply, adjustable to 18V and 1.5A
Variable power supply (0-20V_{DC})
Variable power supply (0-20V)
Variable AC supply, 60 Hz, 20-120 volts with test leads
Variable DC power supply (regulated)
Volt ohmmeter
Voltmeter
Wire markers (numbered tape markers), at least half as many as the number of transformer connections
Zener diode, 5.1V, 1W

MODULE 5: SEMICONDUCTOR DEVICES AND APPLICATIONS

CROSS-REFERENCE TABLE OF INSTRUCTIONAL MATERIALS

Competency	Instructional Objective	Transparency Master	Handout	Assignment Sheet	Job Sheet	Test Item	Notes
B2	I 1.1-1.6	I 1.1-1.3	I 1.1-1.2	I 1.1-1.2		I 1-17	
B14						V 6	
B18	V 1.4-1.5, 1.8-1.10				V 1.1-1.3	V 4, 8	
B19	V 1.1-1.3, 1.6-1.10	V 1.1-1.4			V 1.1-1.3	V 1-2, 5, 7, 9-13, VII 4, 8	
B20	V 1.8-1.10				V 1.1-1.3		
C1	IV 1.1-1.4, 2.4-2.5				IV 2.1-2.2	IV 1-10, 13, 19, 22, 23, VII 1, 7, 9	
C2	IV 1.2, 1.5, 2.4-2.5		IV 1.1		IV 1.1, 2.1-2.2	IV 16, 18, 20, 21	
C3	IV 1.1, 2.1-2.5	IV 2.1-2.2			IV 2.1-2.2	IV 11-12, 15-18, 24, 25, V 3	
C4	IV 2.4-2.5				IV 2.1-2.2		
C5	XII 1.1-1.5, 1.8	XII 1.1-1.3			XII 1.1, 1.4	VII 12, 13, XII 1,4	
C6	VII 1.1-1.3, 1.5, XII 1.4, 1.7	VII 1.1-1.4			XII 1.3	VII 11, 14-17, XII 2, 8	
C7	XII 1.4					XII 5	
C8	IV 2.4-2.5				IV 2.1-2.2		
C9	IV 2.4, XII 1.6, 1.8				IV 2.1, XII 1.2, 1.4	XII 7	
D1	II 1.2-1.3, 1.7-1.8, III 1.3-1.5	II 1.1, III 1.1	III 1.1-1.2		II 1.1-1.2, III 1.1	III 13-15	
D2	II 1.1-1.6					II 1-13, VII 5, 10	

Competency	Instructional Objective	Transparency Master	Handout	Assignment Sheet	Job Sheet	Test Item	Notes
D3	VIII 1.1-1.4, 2.1-2.5	VIII 1.1-1.2, 2.1-2.3	VIII 1.1-1.4, 2.1			VII 3, 6, VIII 1-23	
D4	VIII 2.6-2.8, IX 1.5-1.7				VIII 2.1-2.3, IX 1.1-1.2		
D5	XV 1.2-1.3			XV 1.1		XV 4, 12	
D6	XV 1.2, 1.3					XV 8-9	
D7	XV 1.2					XV 26	
D8	XV 1.2					XV 25	
D9	XI 2.1-2.2				XI 2.1	XI 9	
D10	XI 1.2-1.5			XI 1.1	XI 1.1	XI 1-4, 11-12	
D11	XI 2.1-2.2			XI 2.1	XI 2.1	XI 6-8	
D12	VII 1.5					VII 18-19	
D13	VI 1.1-1.6	VI 1.1-1.2	VI 1.1-1.2		VI 1.1	VI 1-15	
D14	VIII 1.5, 2.6-2.8				VIII 1.1, 2.1-2.3		
D15	XI 1.5, 2.2				XI 1.1, 2.1		
D16	XII 1.3, XIV 1.5				XIV 1.2	XI 5, 12	
D17	XIV 1.5				XIV 1.2		
E1	IX 1.1-1.4	IX 1.1-1.2				IX 1-3, 7-8, 10-11, 13-18	
E2	XV 1.1-1.3	XV 1.1				XV 1-4, 6-7, 10, 12, 18-24	
E3	X 1.4-1.11	X 1.2-1.6	X 1.1		X 1.1-1.4	X 1-26	
E4	IX 1.6-1.7, XIV 1.1-1.4			XIV 1.1	IX 1.1-1.2, XIV 1.1	IX 3, XIV 1-29	
E5	XV 1.4-1.6		XV 1.1			XV 5, 11, 13-17	
E6	X 1.11, XVI 1.1-1.4				X 1.1-1.4	XVI 1-12	

Competency	Instructional Objective	Transparency Master	Handout	Assignment Sheet	Job Sheet	Test Item	Notes
E7	IX 1.4					IX 4-6, 9, 12, 16	
E8	X 1.11				X 1.1-1.4		
F1	XIII 1.1-1.3	XIII 1.1-1.4		XIII 1.1	XIII 1.1	XIII 2, 3, 5	
F2	XIII 1.1-1.3	XIII 1.1-1.4		XIII 1.1	XIII 1.3	XIII 1, 7	
F3							in Receivers and Transmitters
F4	XIII 1.1-1.3	XIII 1.1-1.4		XIII 1.1	XIII 1.1	XIII 4-6	
F5	XIII 1.4b				XIII 1.2	XIII 6	
F6							In Receivers and Transmitters
F7	XIII 1.4b				XIII 1.2	XIII 6	
H4	XIII 1.4b, c				XIII 1.2, 1.3		

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT I: SEMICONDUCTOR MATERIALS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to discuss the composition of semiconductor materials, the doping process and P-N junction characteristics. This knowledge will be demonstrated by completion of assignment sheets and the unit test to specified score.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Match terms related to semiconductor devices with definitions.

1.2 Describe uses and characteristics of semiconductors.

1.3 Describe the doping process to produce P- and N-type materials.

1.4 Select true statements about the characteristics of N- and P-type semiconductors.

1.5 Explain P-N junction components and operation.

1.6 Describe forward and reverse biasing of P-N junctions. (competency B2)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT I: SEMICONDUCTOR MATERIALS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the Instructor

D. Lesson plan

   1. Lesson 1: SEMICONDUCTOR MATERIALS

      a. Information outline

      b. Transparency masters

         TM 1.1: Conductors and insulators
         TM 1.2: Semiconductor crystal structures
         TM 1.3: P-N junction

      c. Handouts

         HO 1.1: Forward and reverse bias
         HO 1.2: P-N junction characteristic curves

      d. Assignment sheets

         AS 1.1: Forward and reverse bias
         AS 1.2: P-N junction characteristic curves

      e. Answers to assignment sheets

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Grob, Bernard. Basic Electronics. 5th ed. New York: McGraw-Hill, 1984.
2. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.
3. Hughes, Fredrick W. Basic Electronics: Theory and Experimentation. Englewood Cliffs, N.J.: Prentice-Hall, 1984.
4. Malvino, Albert Paul. Semiconductor Circuit Approximations. 4th ed. New York: McGraw-Hill Book Co., 1985.

5. Schuler, Charles A. Electronics: Principles and Applications. New York: McGraw-Hill, 1979.

6. Weir, Gregory. Fundamentals of Mathematics: Outline and Review Problems for Electronic Circuit Fundamentals. Englewood Cliffs, N.J.: Prentice-Hall, 1987.

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1. Hartman, Lonnie. Basic Electronics. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

2. Vorderstrasse, Ron. General Electronics Technician. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

NOTES TO THE INSTRUCTOR

A. Suggested supplemental material

1. Semi-conductor Materials (E87-310, videotape). Sedalia, MO: The Media Center, State Fair Community College, 1987. (Available for purchase from SFCC; available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT I: SEMICONDUCTOR MATERIALS

LESSON 1: SEMICONDUCTOR MATERIALS

I. Terms and definitions

A. Acceptor atoms--accept electrons from neighboring atoms, creating holes (P-type semiconductor); has had a trivalent impurity added to crystal structure

B. Avalanche--massive current flow caused by excessive reverse voltage. Free electrons strike valence electrons, knocking them from orbit which, in turn, strike other valence electrons, knocking them free.

C. Barrier voltage--voltage across the depletion region

D. Breakdown voltage--reverse voltage at which the resistance of the junction is overcome and a large current is forced to flow

E. Crystal--structure formed by atoms covalently bonding together

F. Depletion region--area near the junction where positive and negative charges form the barrier voltage

G. Donor atom--pentavalent impurity added to the crystal structure to produce free electrons

H. Doping--addition of impurities to a pure material

I. Extrinsic--material with impurities added

J. Forward bias--external voltage applied to a P-N junction. The positive lead goes to a P-type material and the negative lead goes to an N-type material.

K. Free electrons--electron loosely bound to an atom

L. Germanium--semiconductor material

M. Hole--positively charged vacancy made when a valence electron leaves the outer orbit of an atom

N. Hole flow--movement of holes

O. Intrinsic--material with no impurities

P. Majority carriers--highest charge in material

Q. Minority carriers--least charge in material

R. N-type material--semiconductor material with an excess of free electrons produced by doping

S. P-type material--semiconductor material with an excess of holes produced by doping

T. Reverse bias--external voltage applied to a P-N junction. The positive lead goes to N-type material and the negative lead goes to P-type material.

U. Semiconductor--material that has electrical properties of both a conductor and an insulator

V. Silicon--semiconductor material

II. Uses and characteristics

A. Many electronic devices used today are constructed from semiconductor materials.

1. The most common of these devices are diodes, transistors and integrated circuits.

2. Semiconductors are used primarily as current control devices in electronic circuits and equipment.

B. Advantages of semiconductors

1. Small and lightweight

2. Low power consumption; operate on low voltages

3. Reliable and durable

4. Inexpensive

C. Disadvantages of semiconductors

1. Affected by high temperatures

2. Can be damaged by reverse voltages exceeding device limits

D. A semiconductor conducts current better than an insulator but not as good as a conductor. **(TM 1.1)**

E. Semiconductor characteristics result from the way atoms interconnect with each other to form the material. **(TM 1.2)**

1. Conductors have few electrons in the outer shell.

2. Insulators have a nearly full outer shell.

3. Semiconductors have a valence of four because there are four electrons in the outer orbit of the atom.

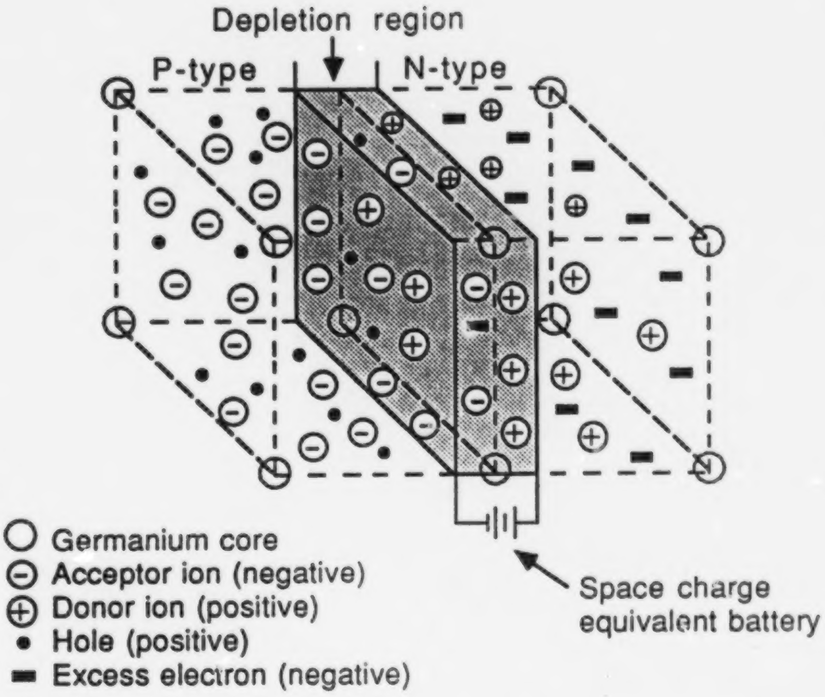
a. Since eight is the maximum number of electrons in an outer orbit, a semiconductor atom can take four more electrons.

b. Semiconductor atoms share electrons in the valence shell, forming a stable lattice structure called a crystal.

c. This sharing of valence electrons is called covalent bonding.

4. The material formed is called pure or intrinsic and is neither positive nor negative.

F. Silicon and germanium are two important semiconductor materials.


Depletion region
P-type
N-type
○ Germanium core
⊖ Acceptor ion (negative)
⊕ Donor ion (positive)
• Hole (positive)
▬ Excess electron (negative)
Space charge equivalent battery

III. Doping--addition of impurities to an intrinsic semiconductor to form a positive (P-type) or negative material (N-type). After doping, material is an extrinsic semiconductor. (TM 1.2)

A. Impurities produce a polarity by adding electrons or holes.

B. Types of impurities added

1. Pentavalent materials have atoms with five valence electrons.

   a. Arsenic

   b. Phosphorus

   c. Antimony

2. Trivalent materials have atoms with three valence electrons.

   a. Boron

   b. Gallium

   c. Aluminum

C. When a pentavalent impurity is added to an intrinsic semiconductor material, some of the pentavalent atoms replace the pure atoms in the crystal structure.

1. These new atoms (donor atoms) share four valence electrons with the adjacent atoms.

2. The fifth electron (free electron) is loosely attached to the pentavalent atom and is easily moved.

D. When an intrinsic semiconductor material is doped with a trivalent material, some trivalent atoms replace atoms in the semiconductor.

    1. These trivalent atoms share three electrons with adjacent atoms.

    2. The lack of a fourth electron creates a hole in the covalent bond.

E. Though there are positive (hole) and negative (electron) charges in P- and N-type semiconductors, the material is not charged.

    1. Since the atoms have the same number of electrons and protons, the material is neutral (has no charge).

    2. The movement of charges does not cause the material to become charged.

    3. N- and P-type semiconductors have a lower resistance to current flow than pure semiconductors.

IV. N- and P-type semiconductors

A. N-type (negative) semiconductor--crystal that has many donor atoms

    1. When voltage is applied to N-type material, free electrons flow toward the positive voltage.

        a. Donor atoms supply free electrons.

        b. Other free electrons are produced when electrons break loose from the covalent bond.

    2. Holes, caused by the absence of electrons in the covalent bond, are positive.

        a. Holes can attract and hold electrons.

        b. Holes are attracted to the negative terminal of the applied voltage.

    3. Electrons, which outnumber holes in N-type materials, are the majority carriers. Holes are the minority carriers.

B. P-type (positive) semiconductor--material that has more positively charged holes than negatively charged electrons (doped with trivalent atoms)

    1. Excess holes attract and release electrons in the crystal, causing holes to drift or move about.

    2. Atoms that accept other electrons are called acceptor atoms.

    3. Holes are the majority carriers and electrons are the minority carriers.

    4. Voltage applied to the material causes holes to move toward the negative terminal of the applied voltage and electrons to move toward the positive terminal of the applied voltage.

V. P-N junction formed by joining P- and N-type materials (TM 1.3)

A. Methods of joining materials

    1. Epitaxial growth

    2. Diffusion

3. Alloyed

B. When a junction is formed, electrons from the N-type material cross the junction and combine with the holes in the P-type material.

C. The depletion region is the small region on either side of the junction which is void of majority carriers.

D. Action in the depletion region forms a barrier voltage.

   1. The barrier voltage for silicon is 0.7 volts.

   2. The barrier voltage for germanium is 0.3 volts.

VI. P-N junction bias **(HO 1.1, 1.2)**

A. The P-N junction will conduct current when a voltage, called bias voltage, is applied.

B. Many semiconductors require either forward or reverse bias to operate.

   1. Forward bias

      a. Bias voltage is applied with the positive terminal of the voltage connected to the P-type material and the negative terminal of the voltage connected to the N-type material.

      b. Forward current in a semiconductor is very small until the forward bias exceeds the barrier voltage.

      c. The forward current increases rapidly; if the forward voltage is large enough, the junction can conduct sufficient current to damage the device.

      d. The forward current is the flow of majority carriers.

      e. Forward-biased semiconductors have low resistance.

   2. Reverse bias

      a. Bias voltage is applied with the positive terminal connected to the N-type material and the negative terminal connected to the P-type material.

      b. Reverse current in a semiconductor is the flow of minority carriers.

      c. Generally, a large reverse voltage is required for a semiconductor to have reverse current.

      d. The value of reverse voltage that causes a large increase in reverse current is called the breakdown voltage.

      e. Most devices are not operated in the reverse-breakdown region because the rapid increase in current will damage the device.

C. Large currents cause heat to build up in the junction.

   1. Large amounts of heat can destroy a semiconductor junction.

   2. Semiconductor manufacturers specify operating requirements and limits.

TM 1.1

CONDUCTORS AND INSULATORS

Insulators

- Mica
- Glass
- Shellac
- Paper
- Rubber
- Bakelite
- Fiber
- Air or Vacuum

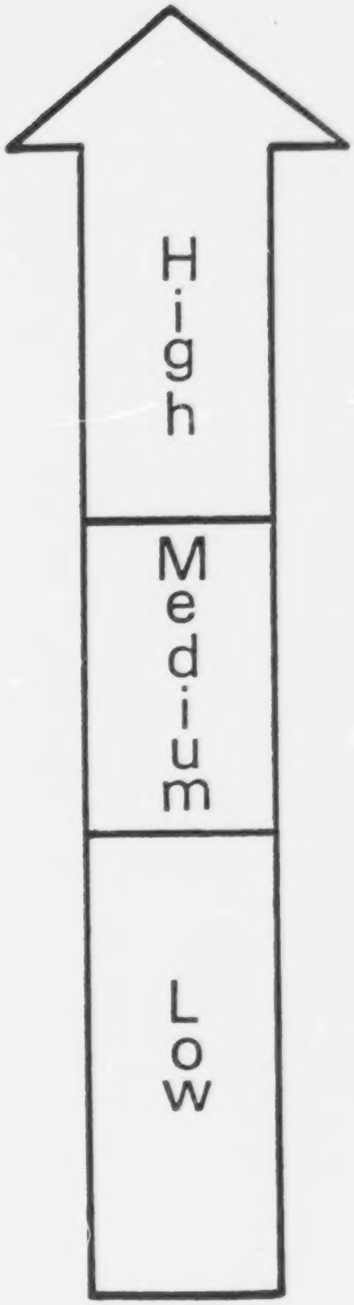
Semiconductors

- Germanium
- Silicon

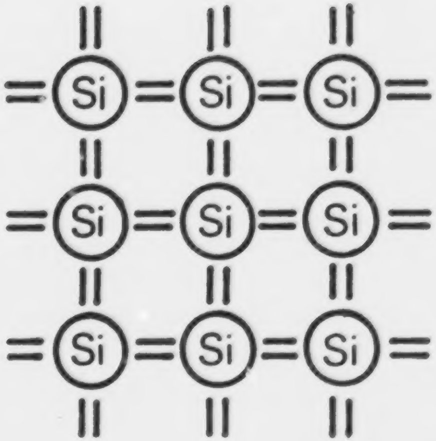
Conductors

- Iron
- Nickel
- Tungsten
- Aluminum
- Gold
- Copper
- Silver

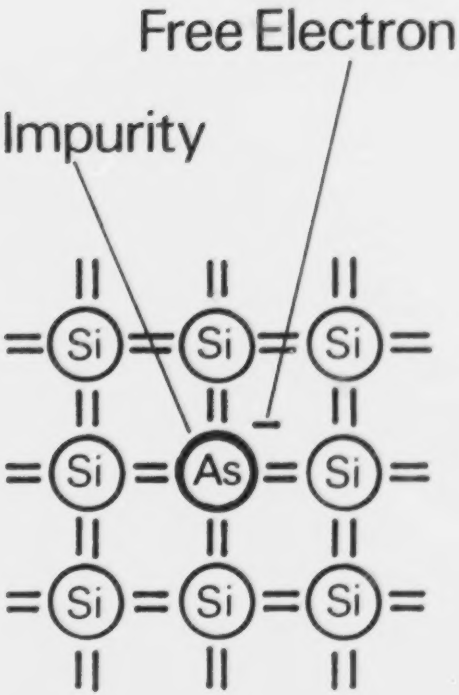
Increasing Resistance



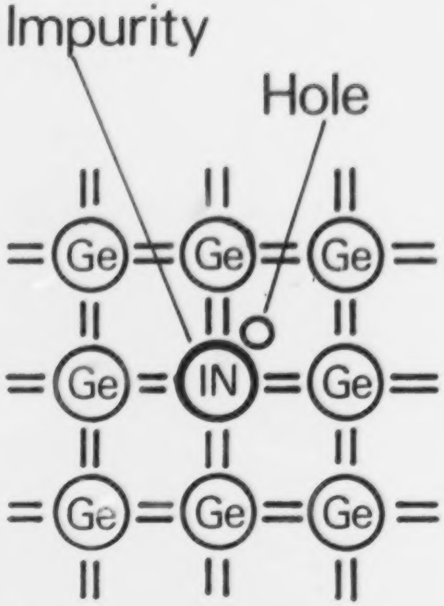
SEMICONDUCTOR CRYSTAL STRUCTURES



Pure Silicon Crystal
Intrinsic

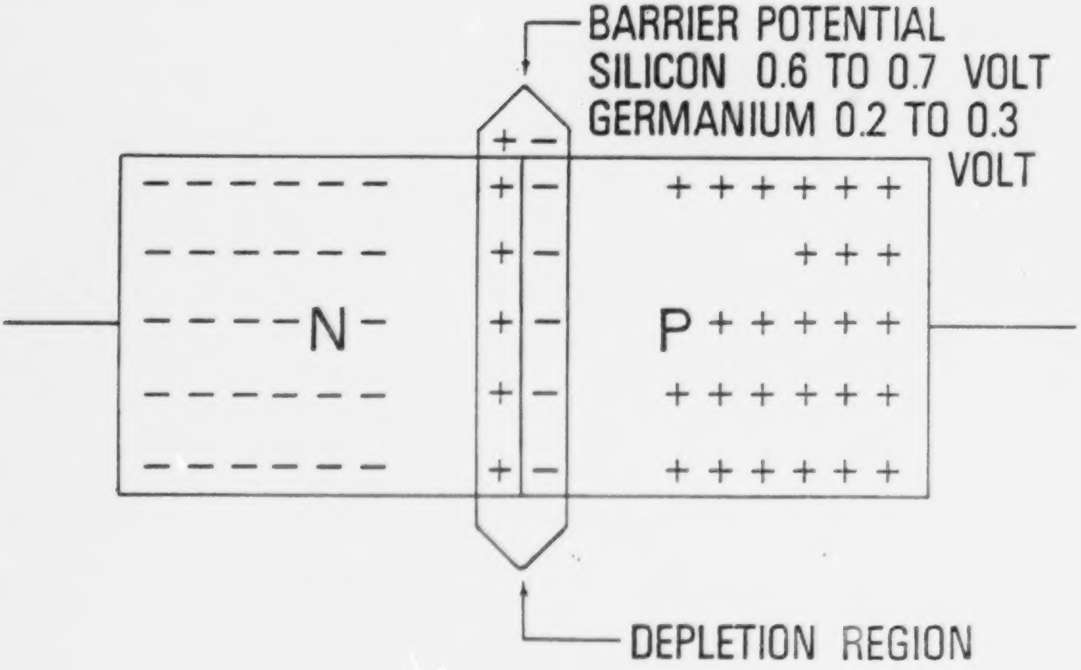

Free Electron
Impurity
Si
As
–

N-Type Silicon
Crystal
Extrinsic


Impurity
Hole
Ge
IN

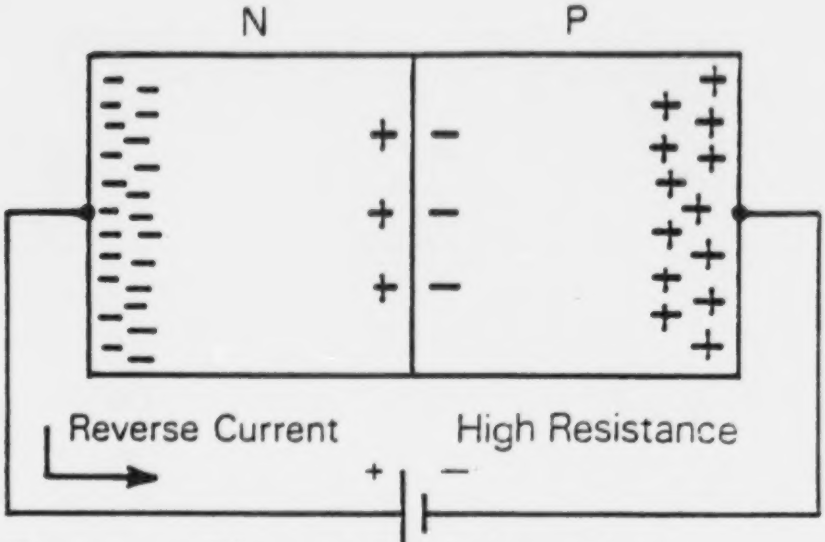
P-Type Germanium
Crystal
Extrinsic

P-N JUNCTION

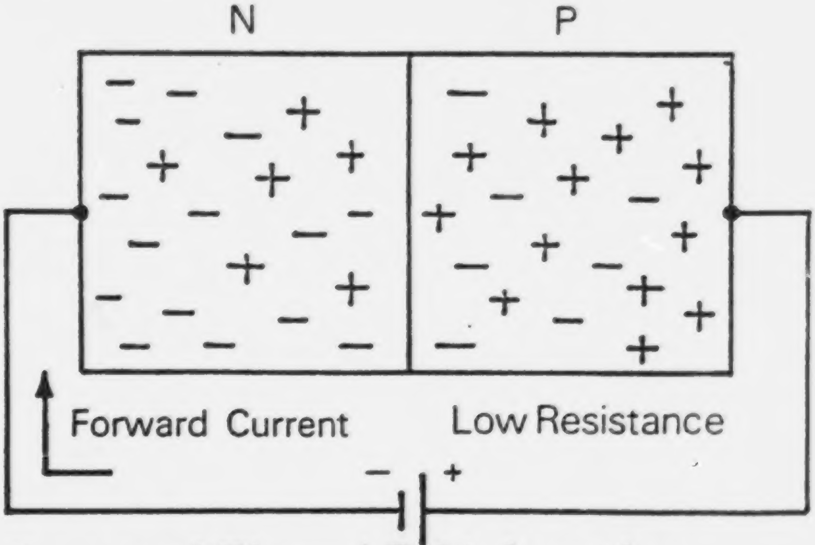

BARRIER POTENTIAL
SILICON 0.6 TO 0.7 VOLT
GERMANIUM 0.2 TO 0.3 VOLT
N
P
+ −
DEPLETION REGION

P-N JUNCTION
Showing Barrier Potential
And
Depletion Region

FORWARD AND REVERSE BIAS


N
P
Reverse Current
High Resistance
+
−

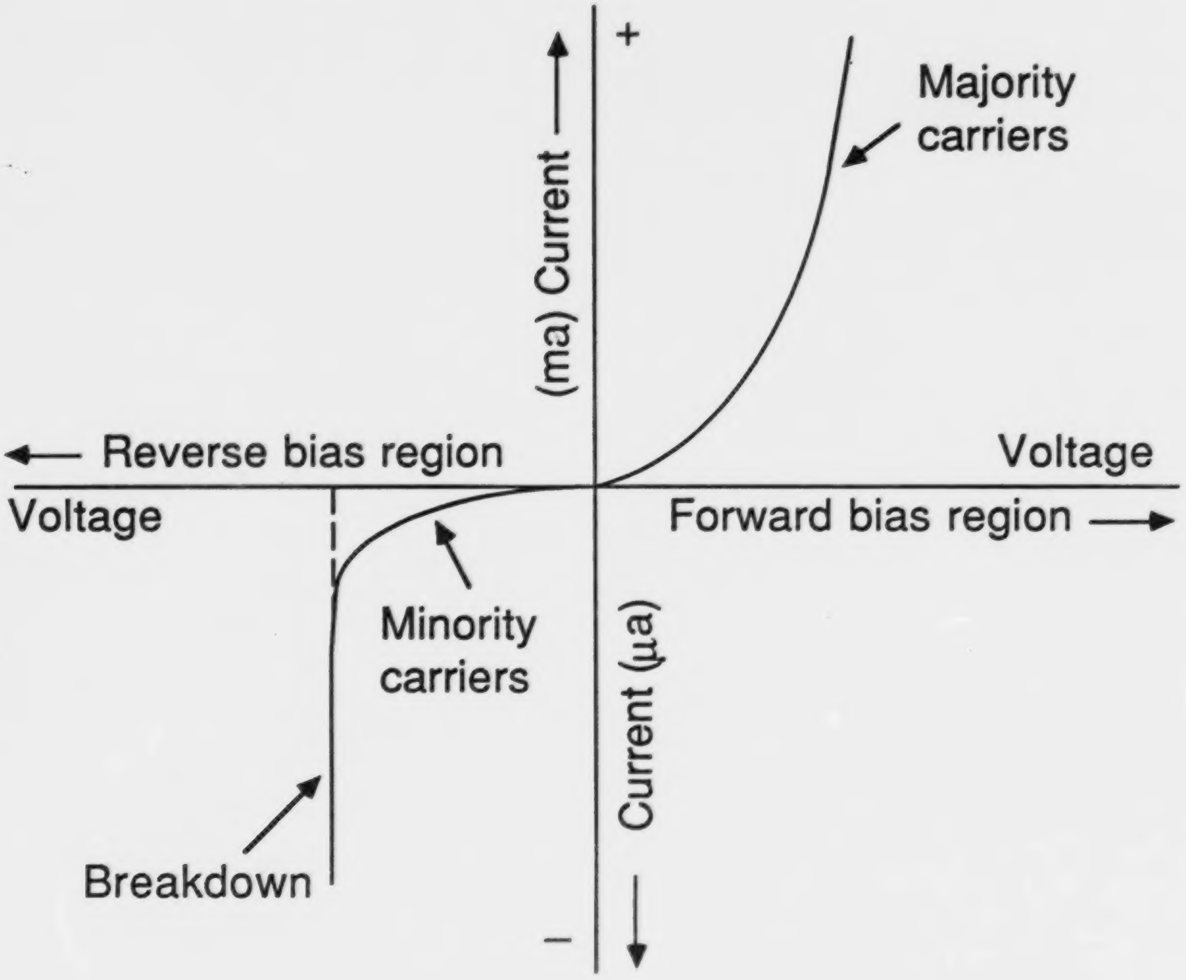
Reverse Biased P-N Junction


N
P
Forward Current
Low Resistance
−
+

Forward Biased P-N Junction

Note— Barrier potential increases and depletion region widens as reverse bias is increased.

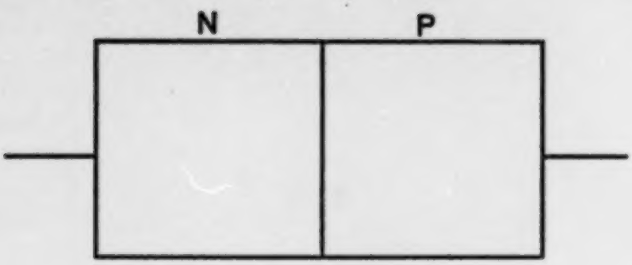
P-N JUNCTION CHARACTERISTIC CURVES



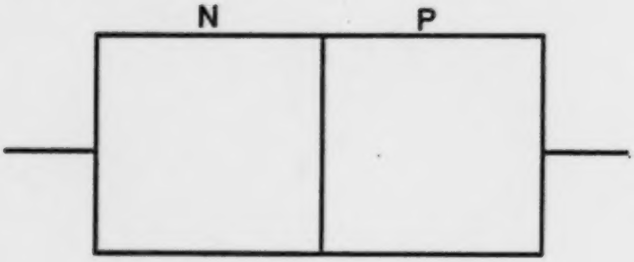
33

FORWARD AND REVERSE BIAS

1. **Draw the schematic symbol for a battery and connect the battery to the P-N junction. Label polarities and show a reverse-bias junction's direction of current flow.**



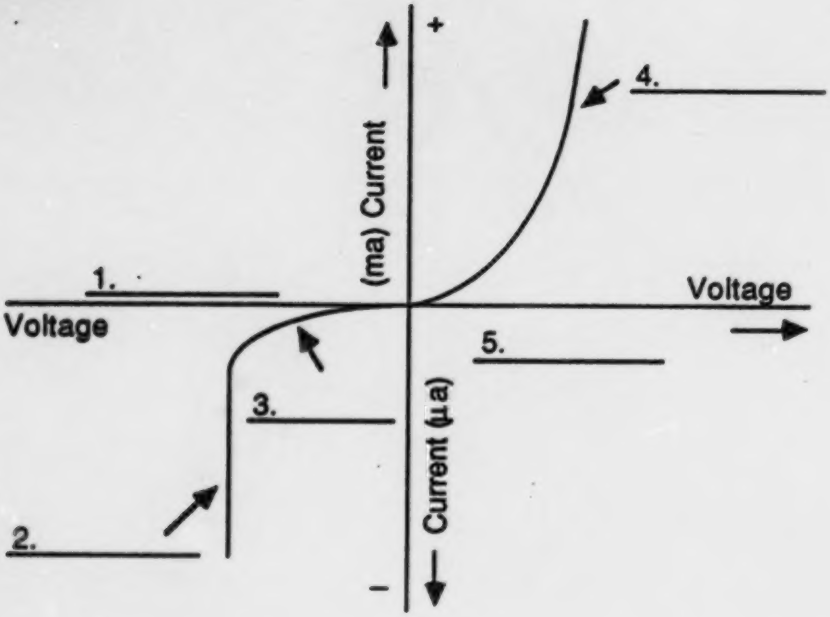
2. **Draw the schematic symbol for a battery and connect it to the P-N junction. Label polarities and show a forward-bias junction's direction of current flow.**



P-N JUNCTION CHARACTERISTIC CURVES

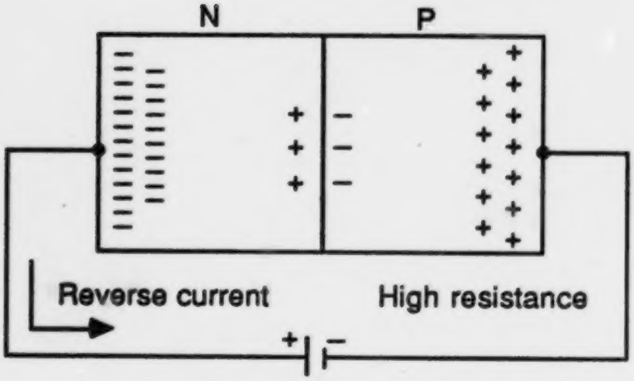
Match the following terms to the characteristic curve illustration below. Use each term only once.

a. Breakdown
b. Forward-bias region
c. Majority carriers
d. Minority carriers
e. Reverse-bias region

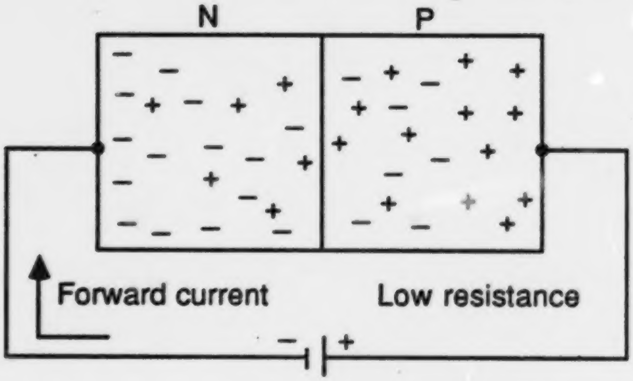

+
4. ____
(ma) Current
1. ____
Voltage
Voltage
5. ____
3. ____
Current (μa)
2. ____
−

ANSWERS TO AS 1.1

1.


N
P
Reverse current
High resistance
+
−

2.


N
P
Forward current
Low resistance
−
+

ANSWERS TO AS 1.2

1. e
2. a
3. d
4. c
5. b

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT I: SEMICONDUCTOR MATERIALS

UNIT TEST

Select the option which best answers the question or completes the statement.

____ 1. Which are two important semiconductor materials in solid-state devices?

a. Silicon and gold
b. Silicon and germanium
c. Germanium and gold
d. Silver and gold
e. Silver and silicon

____ 2. How many valence electrons does an atom of semiconductor material have?

a. Five
b. Four
c. Three
d. Two
e. One

____ 3. Which of the following statements is false?

a. When a difference of potential is applied across a semiconductor material, current flows only in the form of electrons.
b. Semiconductor atoms are bonded together in a crystalline structure through covalent bonding.
c. The conductivity of semiconductor materials can be increased significantly through a process called bias.
d. When pure intrinsic semiconductor materials such as germanium or silicon are doped with a pentavalent element such as arsenic, they become junction N-type semiconductor materials.
e. All of the above

____ 4. Which is true of N-type semiconductor materials?

a. N-type semiconductor materials have electrons as the majority carriers.
b. Holes are the minority carriers in N-type material.
c. Atoms of N-type materials are referred to as donor atoms.
d. Donor atoms are also called pentavalent atoms.
e. All of the above

____ 5. Which is true of P-type semiconductor materials?

a. Atoms of P-type materials are referred to as acceptor atoms.
b. P-type semiconductor materials have electrons as majority carriers.
c. Holes are the minority carriers in P-type materials.
d. Acceptor atoms are also called pentavalent atoms.
e. All of the above

Match terms with appropriate definitions.

____ 6. Two or more atoms sharing electrons in their outer shell to form a stable molecule

____ 7. A pure crystal of material

____ 8. A material to which an impurity has been added

____ 9. A material which has a resistivity between conductors and insulators whose conductivity increases with temperature

____ 10. The process of adding impurities to an intrinsic material

____ 11. The region where N-type and P-type semiconductor materials join together

____ 12. External electric potential applied to a P-N junction

____ 13. The holding together of atoms to form a molecule

____ 14. Electrons in N-type materials and holes in P-type materials

____ 15. Electrons in P-type materials and holes in N-type materials

____ 16. The absence of electrons in a covalent bond

____ 17. The junction area that has no free charges

a. Bias

b. Bonding

c. Covalent bonding

d. Depletion region

e. Doping

ab. Extrinsic material

ac. Hole

ad. Intrinsic material

ae. Majority carrier

bc. Minority carrier

bd. P-N junction

be. Semiconductor

ANSWERS TO UNIT TEST (B2)

1. b
2. b
3. a
4. e
5. a
6. c
7. ad
8. ab
9. be
10. e
11. bd
12. a
13. b
14. ae
15. bc
16. ac
17. d

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT II: DIODES

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to apply theoretical knowledge related to semiconductor diodes, test diodes with an ohmmeter and measure the voltage drop of a diode. This knowledge will be demonstrated by correctly performing procedures outlined in the job sheets and by achieving a specified score on the unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Recognize terms and abbreviations related to diodes.

1.2 Select true statements about the characteristics of diode operation. (competency D1)

1.3 Describe forward and reverse biasing of diodes. (competencies D1 and D2)

1.4 Demonstrate a method of testing diodes with an ohmmeter.

1.5 Describe the effects of temperature on the operation of diodes.

1.6 Use information on data sheets and determine the voltage drop across a diode. (competency D2)

1.7 Test semiconductor diodes. (partial D1, JS 1.1)

1.8 Use a diode as a switch. (partial D1, JS 1.2)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT II: DIODES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

  1. Lesson 1: DIODES

    a. Information outline

    b. Transparency master

      TM 1.1: P-N junction diode characteristic curves

    c. Job sheets

      JS 1.1: Test semiconductor diodes
      JS 1.2: Use a diode as a switch

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

  1. Grob, Bernard. Basic Electronics. 5th ed. New York: McGraw-Hill, 1984.

  2. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.

  3. Hughes, Fredrick W. Basic Electronics: Theory and Experimentation. Englewood Cliffs, N.J.: Prentice-Hall, 1984.

  4. Malvino, Albert Paul. Semiconductor Circuit Approximations. 4th ed. New York: McGraw-Hill Book Co., 1985.

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2. Vorderstrasse, Ron. General Electronics Technician. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. The instructor may wish to use Unit I's TM 1.2 and HO 1.1 in this unit, as well.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT II: DIODES

LESSON 1: DIODES

I. Terms, definitions and abbreviations

  A. Bias--electrical force (voltage) applied to a component (in this unit, a diode)

  B. Diode bias--external voltage applied to the diode

  C. Junction--where P- and N-type material joins

  D. Knee voltage--forward-bias voltage necessary to overcome barrier voltage so that the diode can conduct a large forward current

  E. Load resistor--develops the output voltage and protects the diode from overcurrent (more current than the diode is designed to handle)

  F. Abbreviations

    1. I_O--output current

    2. I_R--maximum reverse current

    3. P_D--power dissipated

    4. PIV or PRV--peak inverse voltage or peak reverse voltage

    5. R_S--current-limiting resistor

    6. V_{in}--voltage in

    7. V_K--knee voltage

    8. V_R--reverse voltage

    9. V_{RMAX}--maximum reverse voltage

    10. V_{RS}--series-resistor voltage

II. Diode characteristics

  A. The word "diode" comes from "di-" or two and "-ode" from electrode.

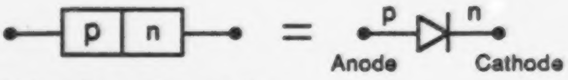
  B. A diode is a two-electrode component with one direction of current.

  C. Diodes can be made of silicon or germanium.

  D. The diode acts like a conductor when biased in one direction and an insulator when biased in the opposite direction.

  E. N- and P-type semiconductor materials are joined together to form the junction diode, or simply diode.

1. When the materials are joined together, a small area (depletion region) on either side of the junction attracts the majority carriers of each material.



Diode schematic symbol

2. The barrier voltage or difference in potential across the junction is 0.7 volts for silicon and 0.3 volts for germanium.

III. Diode bias (TM 1.1)

A. Forward bias

1. The positive terminal of the external voltage is connected to the P-type material and the negative terminal of the external voltage is connected to the N-type material.

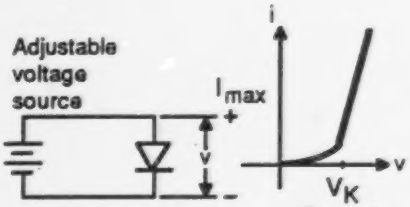
2. Free electrons in the N-type material are attracted to holes in the P-type material.

3. Holes left by the free electrons attract electrons from the external voltage source.

4. The flow of majority carriers (electrons) and movement of minority carriers (holes) occur only when the bias voltage is larger than the barrier voltage.

   a. Until the barrier voltage is overcome, only a small current will flow.

   b. The amount of voltage that causes the large current to flow is the knee voltage.



Forward bias

Forward characteristic

B. Reverse bias

1. The positive terminal of the external voltage is connected to the N-type material; the negative terminal is connected to the P-type material.

2. Reverse bias will cause the depletion region to widen, increasing the junction resistance to current flow.

   a. No current will flow until the breakdown point is reached.

   b. The breakdown voltage (voltage at the breakdown point) forces the diode to overcome the resistance caused by the increased depletion region and conduct.

3. The large reverse bias causes free electrons to cross the depletion region and collide with valence electrons, knocking them from the outer orbit of atoms.

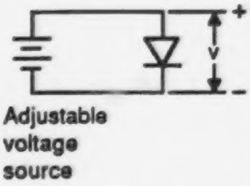
   a. Electrons knocked loose from their orbits now become free electrons which strike other valence electrons, making them free electrons, as well.

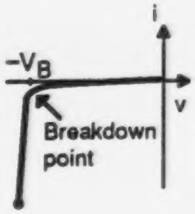
   b. This action is an avalanche effect and the resulting current is called avalanche current.

4. The reverse-bias portion of the graph is interpreted in the same way as the forward-bias portion.

5. Until the reverse bias reaches the breakdown voltage, a small reverse current flows through the diode.

    a. When the diode reaches the breakdown voltage, current increases so rapidly that damage to the diode can occur; most diodes are not operated this way.





    b. Breakdown voltage is also called Peak Inverse Voltage (PIV) or Peak Reverse Voltage (PRV).

    c. Specifications and maximum ratings are given in the manufacturer's data sheets.

IV. Testing diodes

A. Diodes which are out of circuit are checked with an ohmmeter.

B. Some analog meters can produce a large enough current to damage the diode on the lower ohms scale.

    1. Analog meters should be set at Rx100.

    2. Connect the red lead of the ohmmeter to the anode and the black lead to the cathode. Note the reading.

    3. The actual resistance reading is not necessary, but the ratio of forward resistance to reverse resistance is used to determine the condition of the diode.

        a. The ratio should be greater than 1000 to 1. Some high current diodes may be lower.

        b. The diode should test with low resistance when forward biased and high resistance when reverse biased.

        c. A diode that has low resistance in both directions could be shorted.

        d. A diode with high resistance in both directions may be open.

C. Many digital multimeters have a special range setting to test diodes.

V. Effects of temperature on performance

A. Normal operation of diodes is at usual room temperature (70°F); large temperature changes cause operating changes.

B. When the ambient (room) temperature increases, internal temperature of the diode also increases.

    1. This allows electrons to move freely.

    2. V_K will occur at a lower voltage.

C. If the ambient temperature decreases, V_K can occur at a higher voltage.

VI. Data sheets

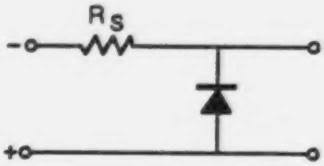
A. Many manufacturers list operating values and maximum ratings for semiconductors in data sheets.

B. If maximum ratings are exceeded, the diode will probably be destroyed.

C. Some information listed on data sheets includes the following.

1. V_{RMAX}--maximum reverse voltage
2. PRV--breakdown voltage
3. I_O--forward current (current in)
4. I_R--maximum reverse current
5. P_D--power dissipated

D. A current-limiting resistor (R_S) is used to keep the maximum rating for the diode within safe limits.

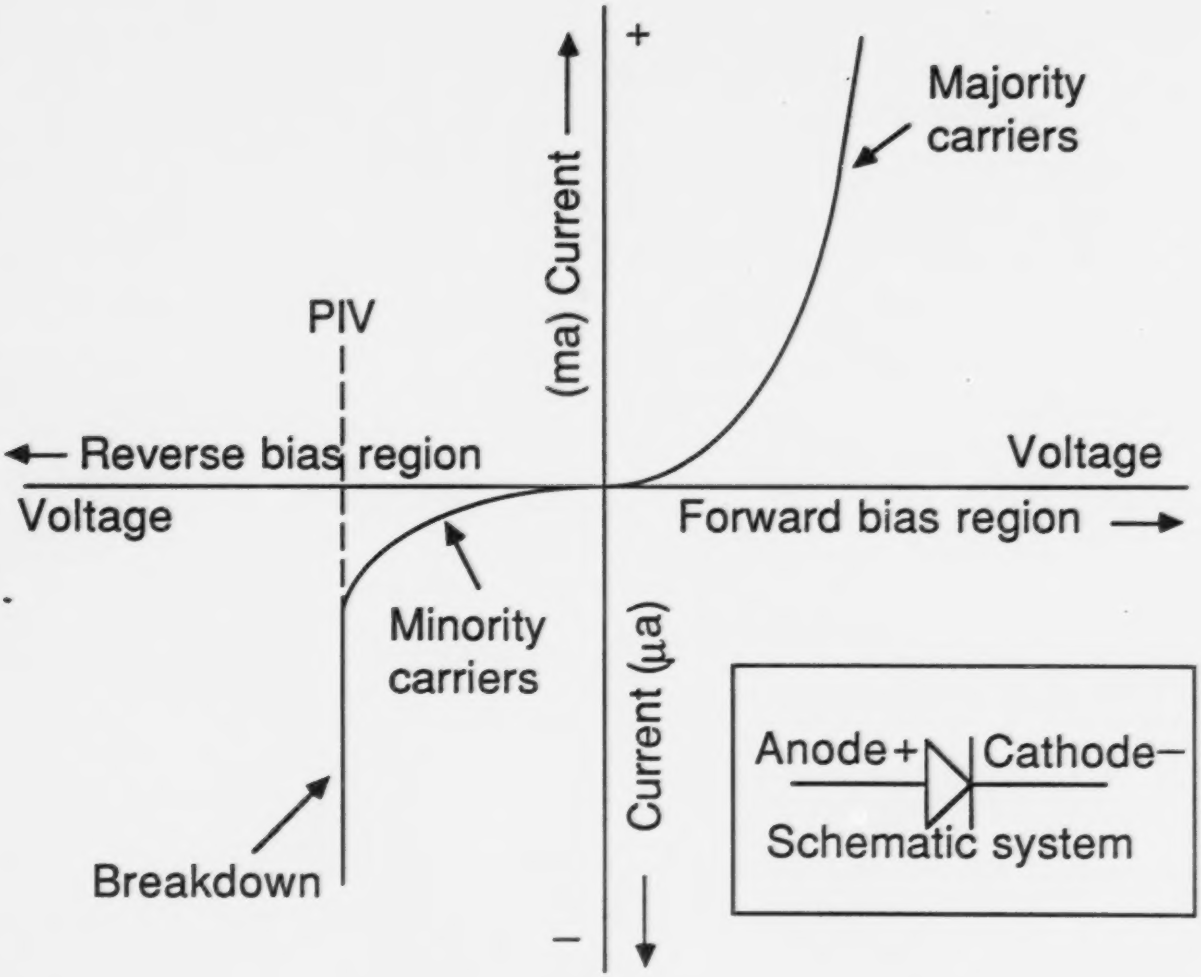


E. The voltage drop of R_S is equal to the source minus V_R.

$V_{RS} = V_{in} - V_R$ and $R_S = V_{RS} / I_O$

TM 1.1

P-N JUNCTION DIODE CHARACTERISTIC CURVES



47

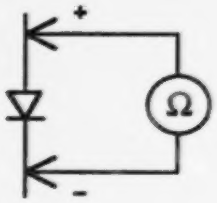
JS 1.1

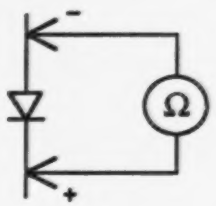
TEST SEMICONDUCTOR DIODES

Equipment:

Ohmmeter
One or more diodes

Procedure:	Evaluation 3	2	1	N
1. Set ohmmeter to Rx100. Place ohmmeter leads on diode leads as shown below in the left-hand figure. Record R_F reading. ______	___	___	___	___
2. Place ohmmeter leads on diode leads as shown in the right-hand figure. Record R_R reading. ______	___	___	___	___
3. Calculate the reverse-to-forward resistance ratio. $R_R / R_F =$ ______	___	___	___	___
Average of above evaluations*	___	___	___	___





*This average is the student's partial evaluation for competency D1: Identify schematic design symbols for semiconductor devices.

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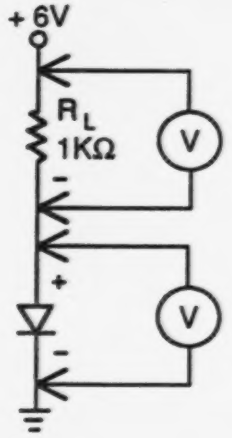
JS 1.2

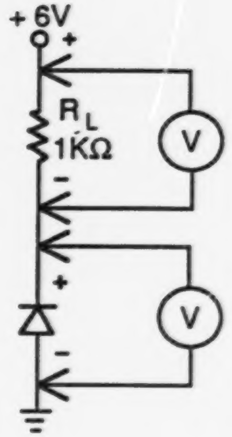
USE A DIODE AS A SWITCH

Equipment:

Variable low-voltage power supply
Voltmeter
1KΩ 0.5w resistor
1N4001 silicon diode or similar type
Breadboard
Hook-up wire

Procedure:	Evaluation 3	 2	 1	 N
1. Construct circuit as shown below in the left-hand figure.	__	__	__	__





2. Adjust power supply to 6v. Measure and record V_F across diode and V_L across R_L. V_F = ______ V_L = ______	__	__	__	__
3. Construct circuit shown in the right-hand figure.	__	__	__	__
4. Measure and record V_F across diode and V_L across R_L. V_F = ______ V_L = ______	__	__	__	__
Average of above evaluations*	__	__	__	__

*This average is the student's partial evaluation for competency D1: Identify schematic design symbols for semiconductor devices.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT II: DIODES

UNIT TEST

Mark "a" if the statement is true and "b" if it false.

____ 1. Majority carriers of P-type semiconductor materials are electrons.

____ 2. The diode is forward-biased when the anode is more positive than the cathode.

____ 3. In a forward-biased diode, both holes and electrons will flow toward the junction.

____ 4. The resistance of a reverse-biased diode is low.

____ 5. When a diode is reverse-biased, its depletion region increases.

____ 6. The arrow in the diode schematic symbol represents the anode.

____ 7. Current flows in the reverse direction through a diode when the breakdown-voltage point is reached.

____ 8. The average voltage drop across a forward-biased silicon diode is 0.3v.

____ 9. With the positive end of a battery placed on P-type material and the negative end placed on N-type material, the P-N junction is forward-biased.

____ 10. The forward resistance of a diode is low.

Select the option which best answers the question or completes the statement.

____ 11. What are majority carriers in N-type semiconductor materials?

a. Holes
b. Neutrons
c. Ions
d. Protons
e. Electrons

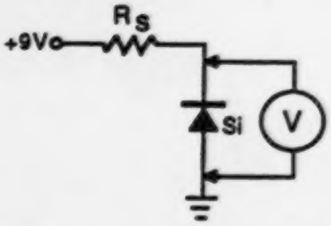
____ 12. With reference to ground, which describes a diode that has -1.3v on its anode and -2.0v on its cathode?

a. Conducting
b. Not conducting
c. Cannot be determined
d. Defective
e. None of the above

___ 13. With the positive lead connected to the anode and the negative lead connected to the cathode, what should an ohmmeter placed across a diode read?

a. Low ohms
b. High ohms
c. 0Ω
d. 2.5Ω
e. 5Ω

___ 14. What would the voltage of the meter shown below read (approximately)?



a. 0V
b. +0.3V
c. +0.7V
d. +5V
e. +9V

___ 15. If three forward-biased silicon diodes are connected in series with a resistor to a +10v source, what is the approximate total voltage drop across the diodes?

a. +0.7v
b. +1.4v
c. +2.1v
d. +10v
e. 0v

___ 16. Which designates breakdown voltage?

a. PRV
b. V_K
c. V_R
d. V_{RMAX}
e. V_{RS}

___ 17. Which is not true of temperature's effect on diode performance?

a. As ambient temperature increases, so does the diode's temperature.
b. Diodes operate well only within a certain temperature range.
c. When room temperature increases, knee voltage occurs at a lower voltage.
d. The optimum room temperature for diode performance is 70°F.
e. Temperature does not affect diode performance.

___ 18. Which describes diodes?

a. Two-electrode components
b. Generally made of silicon or germanium
c. On or off switches, depending on direction of bias
d. Allow current flow in one direction
e. All of the above

ANSWERS TO UNIT TEST (D2)

1. e
2. a
3. a
4. b
5. a
6. a
7. a
8. b
9. a
10. a
11. b
12. a
13. a
14. e
15. c
16. a
17. e
18. e

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT III: DIODE APPLICATIONS AND RECTIFICATION

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to discuss half-wave, clamper and clipper circuits using diodes. This knowledge will be evidenced by achieving a specified score on the job sheet and unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Match diode application terms with definitions.

1.2 Select true statements relating to diode applications.

1.3 Draw the schematic diagram of a half-wave rectifier circuit with positive or negative DC output voltage.

1.4 Draw the schematic diagram of a clamper circuit.

1.5 Construct a half-wave rectifier circuit. (partial D1, JS 1.1)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT III: DIODE APPLICATIONS AND RECTIFICATION

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

    1. Lesson 1: DIODE APPLICATIONS AND RECTIFICATION

        a. Information outline

        b. Transparency master

            TM 1.1: Half-wave rectifier circuits

        c. Handouts

            HO 1.1: Clipper circuit examples
            HO 1.2: Clamper circuits

        d. Job sheet

            JS 1.1: Construct half-wave rectifier circuit

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Grob, Bernard. Basic Electronics. 5th ed. New York: McGraw-Hill, 1984.
2. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.
3. Hughes, Fredrick W. Basic Electronics: Theory and Experimentation. Englewood Cliffs, N.J.: Prentice-Hall, 1984.
4. Malvino, Albert Paul. Semiconductor Circuit Approximations. 4th ed. New York: McGraw-Hill Book Co., 1985.
5. Schuler, Charles A. Electronics: Principles and Applications. New York: McGraw-Hill, 1979.
6. Weir, Gregory. Fundamentals of Mathematics: Outline and Review Problems for Electronic Circuit Fundamentals. Englewood Cliffs, N.J.: Prentice-Hall, 1987.

B. Curriculum guides

1. Hartman, Lonnie. Basic Electronics. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

2. Vorderstrasse, Ron. General Electronics Technician. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT III: DIODE APPLICATIONS AND RECTIFICATION

LESSON 1: DIODE APPLICATIONS AND RECTIFICATION

I. Terms and definitions

  A. Clamper--circuit that produces a shift in the DC output voltage

  B. Clipper--circuit that clips or removes part of the input signal

  C. Frequency--number of times a complete cycle occurs in one second

  D. Half wave--circuit that uses or conducts half of the input waveform

  E. Rectification--ability to change alternating current (AC) to a pulsating direct current (DC) or ripple

  F. Rectifier circuit--converts AC voltages to pulsating DC voltages

  G. Ripple--variations in the DC voltage output of rectifier circuits

II. Semiconductor diodes applications

  A. Detection of signals

  B. Electronic switch

  C. Circuit protection

  D. Rectification

    1. Semiconductor diodes are most widely used for rectification.

    2. Diodes used in this application are often called rectifier diodes or rectifiers.

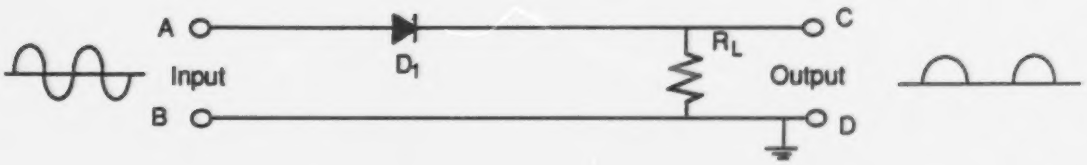
    3. Silicon diodes are the most popular material for rectifiers.

      a. Higher current-handling capability

      b. Higher PIV (peak inverse voltage)

III. Rectification (TM 1.1)

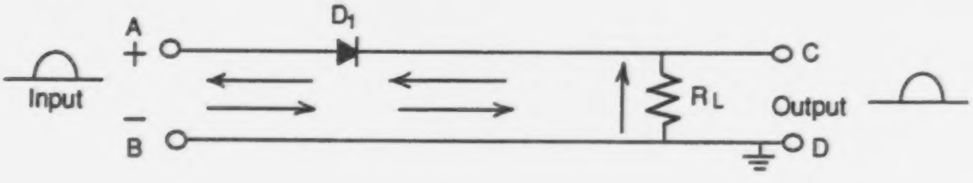
  A. An AC input on the following circuit places points A (+) and B (-) on the positive alternation of the sine wave.


A
C
R_L
Input
D1
Output
B
D

1. The polarity of points A and B will reverse with negative alternation of the sine wave (A - and B +).

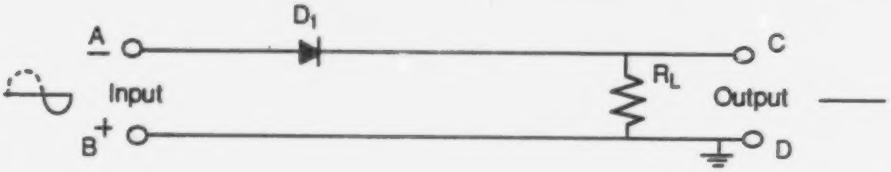
2. During the positive portion of the sine-wave input, point A is positive with respect to point B.

B. The diode (D_1) is forward-biased and conducts in the direction shown through the load resistor (R_L).


D1
A
+
C
Input
R L
Output
–
B
D

C. Output follows input during positive alternation.

D. During the negative alternation of the sine wave, point A is negative with respect to point B.


D1
A
–
C
R L
Input
Output
B
+
D

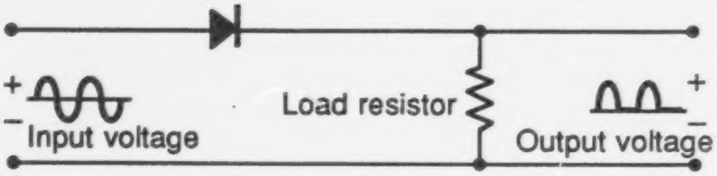
1. D_1 is reverse-biased.

2. No current will flow.

3. No output will occur.

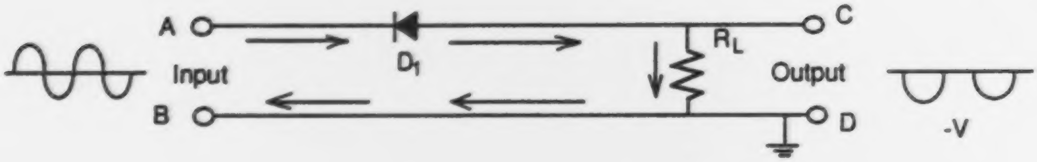
E. The next positive alternation of the input sine wave will forward-bias D_1 and current will flow.

F. This pattern of conducting on the positive alternation and not conducting on the negative alternation produces DC ripple.

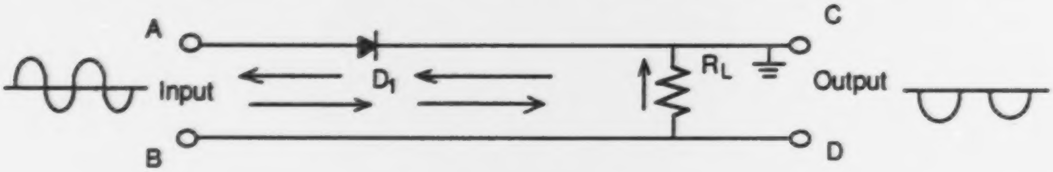

+
–
Input voltage
Load resistor
+
–
Output voltage

G. Input and output frequencies are the same.

H. By reversing the diode, the output will be negative.



I. If point C is made the reference with respect to point D, output will be negative.

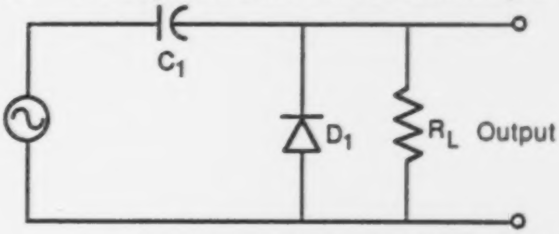


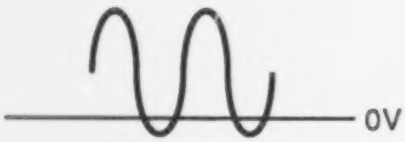
J. Since these circuits only use or conduct on half of the sine wave, they are half-wave rectifier circuits.

1. Other circuits that use both alternations of the input sine wave are full-wave rectifiers.
2. Rectifier action in a half-wave application is also known as a **clipper** because it removes or clips half the sine wave. (HO 1.1)
    a. If output is negative, it is a positive clipper.
    b. If output is positive, it is a negative clipper.

IV. Clamper (HO 1.2)

A. A clamper shifts the DC level of the output.





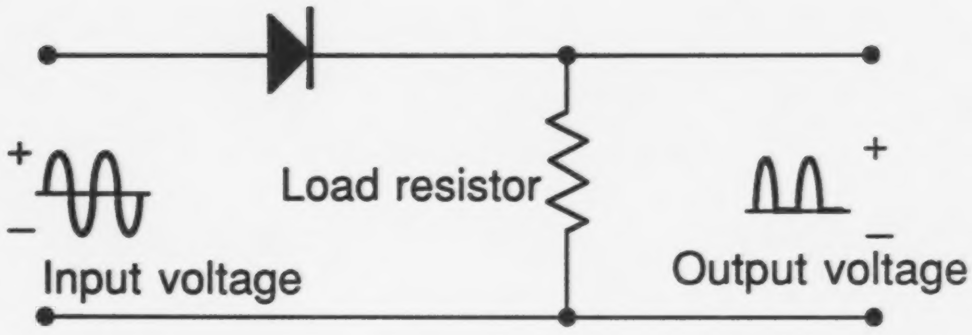
1. On the negative portion of the input sine wave, the diode conducts and charges the capacitor (C_1) to the value of the input voltage.
2. Values of R_L and C_1 form a long time constant, allowing the capacitor to remain nearly fully charged between negative peaks.
3. The sum of the input voltage and the charge of the capacitor cause the waveform to be above the 0v line.

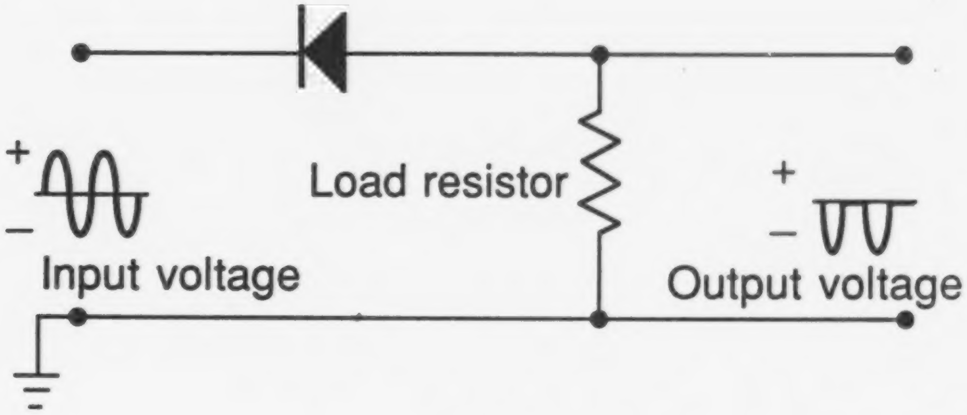
B. If the diode is reversed, output will be negative.

C. Clampers used in television receivers (known as DC restorers) shift the level of the video signal.

TM 1.1

HALF-WAVE RECTIFIER CIRCUITS


+
–
Input voltage
Load resistor
+
–
Output voltage


+
–
Input voltage
Load resistor
+
–
Output voltage

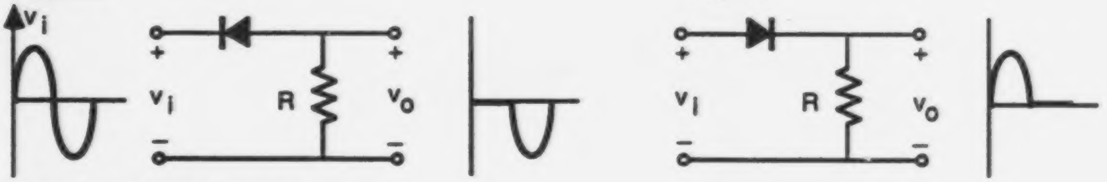
HO 1.1

CLIPPER CIRCUIT EXAMPLES

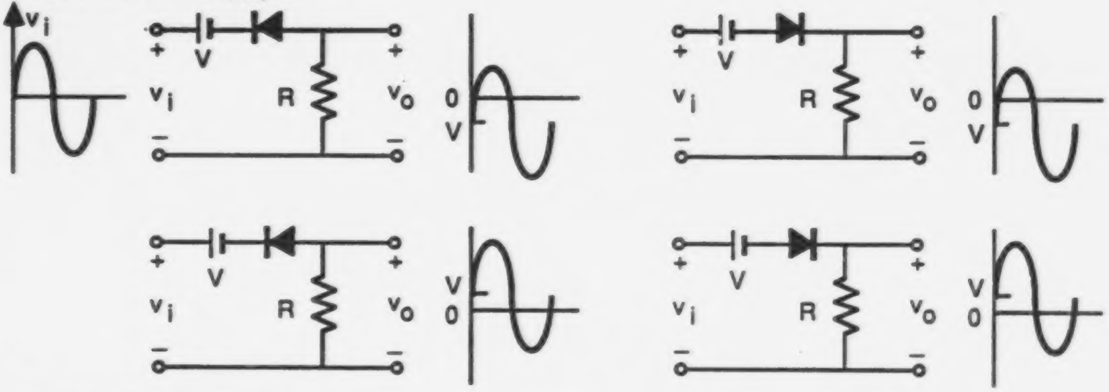
Simple series clippers

Positive

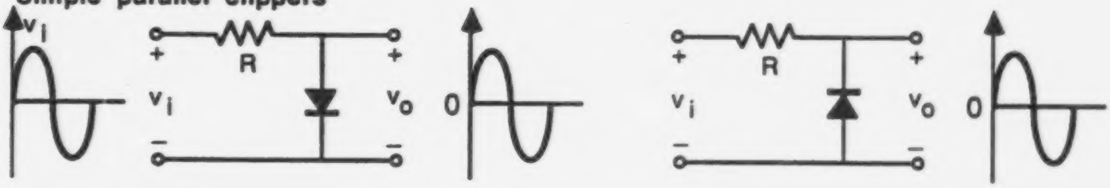
Negative


vi
+
vi
–
R
+
vo
–
+
vi
–
R
+
vo
–

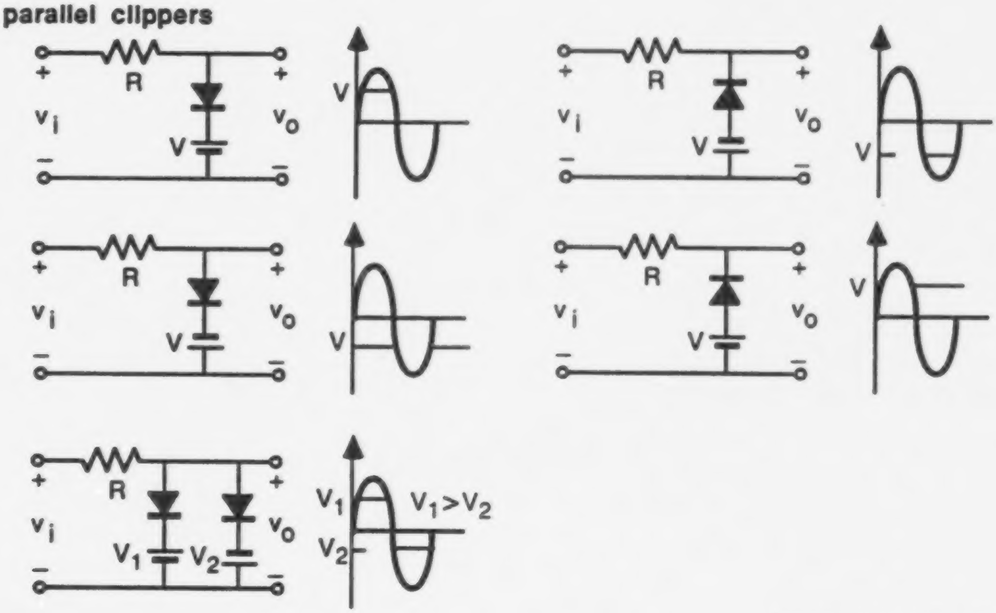
Based series clippers


vi
+
V
vi
–
R
+
vo
–
0
V
+
V
vi
–
R
+
vo
–
0
V
+
V
vi
–
R
+
vo
–
V
0
+
V
vi
–
R
+
vo
–
V
0

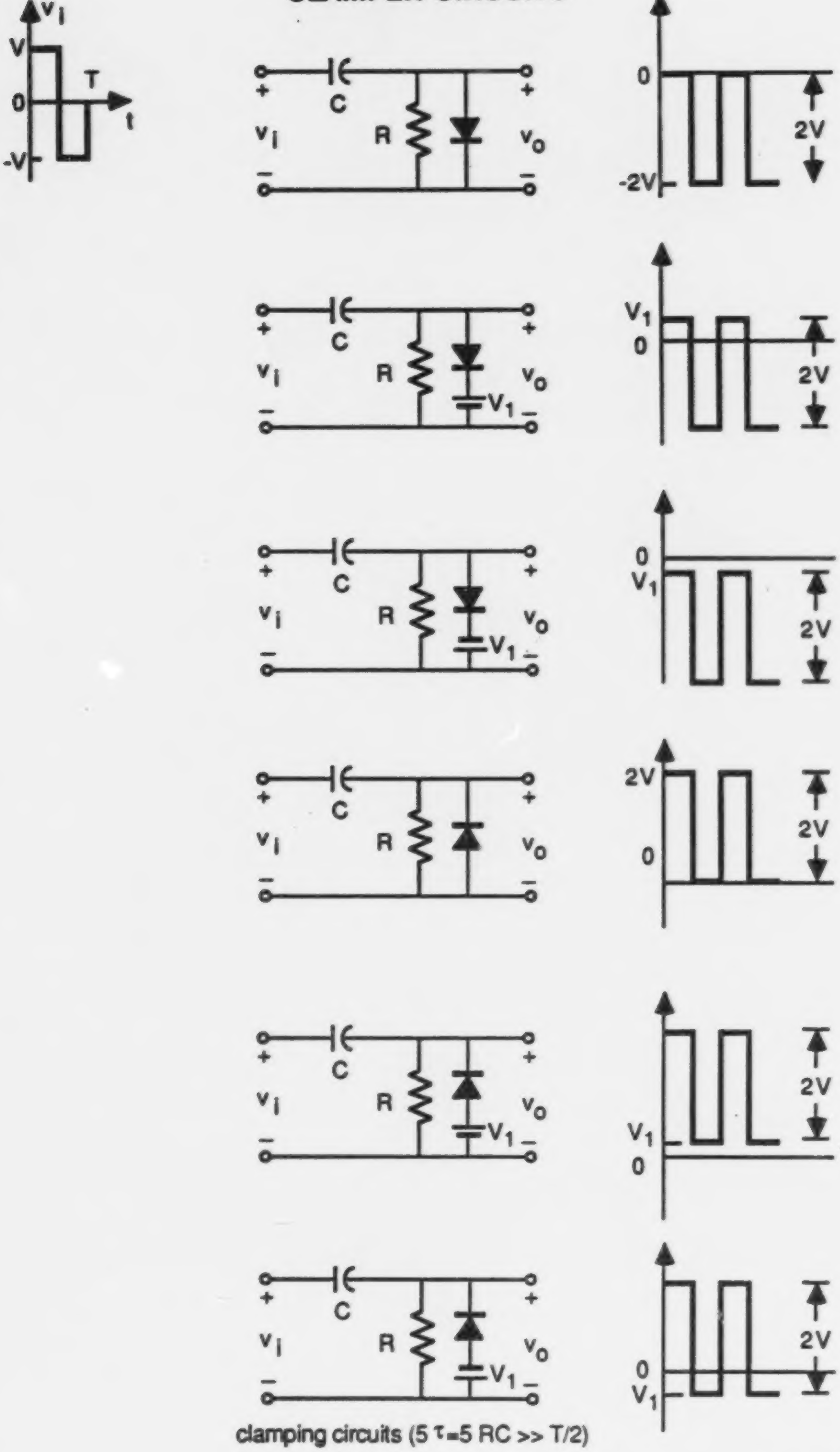
Simple parallel clippers


vi
+
R
vi
–
+
vo
–
0
+
R
vi
–
+
vo
–
0

Biased parallel clippers


+
R
vi
V
–
+
vo
–
V
+
R
vi
V
–
+
vo
–
V
+
R
vi
V
–
+
vo
–
V
+
R
vi
V
–
+
vo
–
V
+
R
vi
V1
V2
–
+
vo
–
V1
V1 > V2
V2

CLAMPER CIRCUITS


v_i
V
0
T
t
-V
+
C
v_i
R
v_o
−
0
-2V
2V
V_1
0
2V
0
V_1
2V
2V
2V
0
2V
V_1
0
2V
0
V_1

clamping circuits (5 τ=5 RC >> T/2)

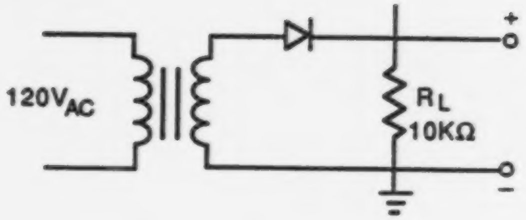
JS 1.1

CONSTRUCT HALF-WAVE RECTIFIER CIRCUIT

Equipment:

Oscilloscope
12v transformer
10KΩ 0.5w resistor
IN4001 diode or similar type
Breadboard
Hook-up wire

Procedure:	**Evaluation** 3	2	1	N
1. Construct circuit shown below.	___	___	___	___



2. Apply power to circuit. Observe waveform across R_L with oscilloscope. Measure and record voltage.	___	___	___	___

V_{out} = ________

3. Remove power from circuit. Turn diode around in circuit.	___	___	___	___
4. Apply power to circuit. Observe waveform across R_L with oscilloscope. Measure and record voltage.	___	___	___	___

Waveform = ________________ Diode reversed: V_{out} = ______

5. Return equipment to storage area.	___	___	___	___
Average of above evaluations*	___	___	___	___

*This average is the student's partial evaluation for competency D1: Identify schematic design symbols for semiconductor devices.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT III: DIODE APPLICATION AND RECTIFICATION

UNIT TEST

Match terms with appropriate definitions.

____ 1. Circuit that converts AC voltages to pulsating DC voltages

____ 2. Circuit that removes part of the input signal

____ 3. Variations in the DC voltage output of rectifier circuits

____ 4. Circuit that produces a shift in the DC output voltage

____ 5. Number of times that a complete cycle occurs in one second

____ 6. Circuit that uses or conducts half of the input waveform

a. Clamper

b. Clipper

c. Frequency

d. Half wave

e. Rectifier circuit

ab. Ripple

Mark "a" if the statement is true and "b" is the statement is false.

____ 7. Diodes cannot rectify AC voltage.

____ 8. A semiconductor diode can be called a rectifier diode.

____ 9. Silicon diodes are the most popular diodes used as rectifiers.

____ 10. A diode can be used as an electronic switch.

____ 11. A circuit that produces a shift in the DC output voltage is called a clipper.

____ 12. Pulsating AC is called ripple.

13. Draw the schematic diagram of a half-wave rectifier circuit.

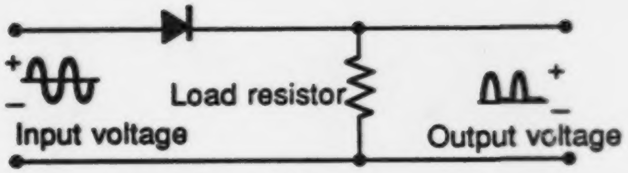
14. Draw the schematic diagram of a clamper circuit.

15. Draw the schematic diagram of a half-wave rectifier circuit that produces a negative-output voltage.

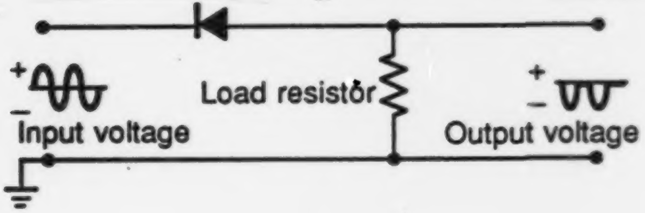
ANSWERS TO UNIT TEST

1. e
2. b
3. ab
4. a
5. c
6. d
7. b
8. a
9. a
10. a
11. b
12. b

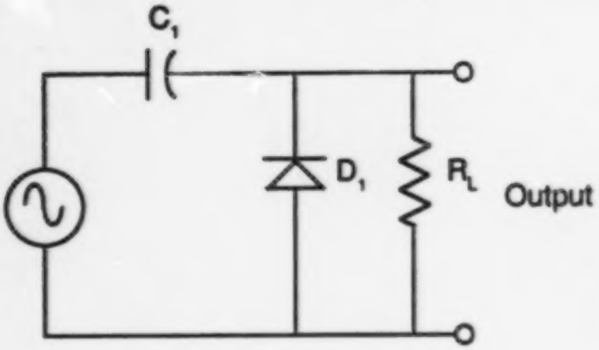
13.


+
–
Input voltage
Load resistor
+
–
Output voltage

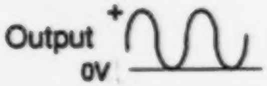
or


+
–
Input voltage
Load resistor
+
–
Output voltage

14.

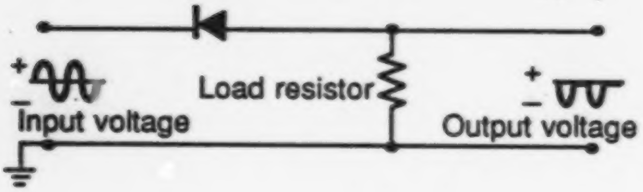


C1
D1
RL
Output



Output
+
0V

15.



+
−
Input voltage
Load resistor
+
−
Output voltage

66

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS
UNIT IV: UNREGULATED POWER SUPPLIES

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to determine transformer configurations and test half-wave and full-wave bridge rectifier circuits. This knowledge will be evidenced by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Match terms concerning unregulated power supplies with definitions. (competencies C1 and C3)

1.2 Identify correct information about transformers. (competencies C1-2)

1.3 Match types of transformers to uses or descriptions.

1.4 Identify types of single-phase transformer connections. (competency C1)

1.5 Determine transformer configurations. (partial C2, JS 1.1)

2.1 Differentiate between true and false information about half-wave rectifiers.

2.2 Draw the schematic diagram of a full-wave circuit.

2.3 Draw the schematic diagram of a bridge rectifier. (competency C3)

2.4 Construct and test a half-wave rectifier circuit. (partial C1-4 and C8-9, JS 2.1)

2.5 Construct and test a bridge rectifier circuit. (competency C1-4 and C8, JS 2.2)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT IV: UNREGULATED POWER SUPPLIES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

  1. Lesson 1: TRANSFORMERS

    a. Information outline

    b. Handout

      HO 1.1: The transformer

    c. Job sheet

      JS 1.1: Determine transformer configuration

  2. Lesson 2: RECTIFIERS

    a. Information outline

    b. Transparency masters

      TM 2.1: Conventional full-wave rectifier
      TM 2.2: Bridge rectifier

    c. Job sheets

      JS 2.1: Construct and test a half-wave rectifier circuit
      JS 2.2: Construct and test a full-wave bridge rectifier circuit

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

  1. Grob, Bernard. Basic Electronics. 5th ed. New York: McGraw-Hill, 1984.

  2. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.

3. Hughes, Fredrick W. Basic Electronics: Theory and Experimentation. Englewood Cliffs, N.J.: Prentice-Hall, 1984.

4. Malvino, Albert Paul. Semiconductor Circuit Approximations. 4th ed. New York: McGraw-Hill Book Co., 1985.

5. Schuler, Charles A. Electronics: Principles and Applications. New York: McGraw-Hill, 1979.

6. Weir, Gregory. Fundamentals of Mathematics: Outline and Review Problems for Electronic Circuit Fundamentals. Englewood Cliffs, N.J.: Prentice-Hall, 1987.

B. Curriculum guides

1. Hartman, Lonnie. Basic Electronics. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

2. Vorderstrasse, Ron. General Electronics Technician. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

NOTES TO THE INSTRUCTOR

A. Suggested supplemental material

1. DC Power Supplies (E-87-320, videotape). Sedalia, MO: The Media Center, State Fair Community College, 1987. (Available for purchase from SFCC; available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT IV: UNREGULATED POWER SUPPLIES

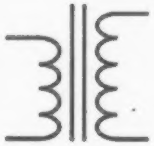
LESSON 1: TRANSFORMERS

I. Terms and definitions

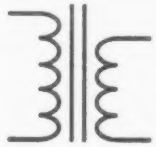
- A. Bridge rectifier--circuit that uses four diodes to convert AC voltage to pulsating DC voltage
- B. Center tap--connection midway between the electrical ends of a resistor or other part of a circuit
- C. Full wave--circuit that uses both alternations of the input waveform to produce an output
- D. Isolation--two circuits that are electrically separate (having no physical connection)
- F. Transformer--device used to step-up (increase) or step-down (decrease) the AC voltage input in a circuit

II. General information **(HO 1.1)**

- A. The relationship between the input and output voltage of a transformer is dependent on the ratio of the number of turns in the primary and secondary.
  1. $$\frac{\text{primary voltage}}{\text{secondary voltage}} = \frac{\text{turns primary}}{\text{turns secondary}}$$
  2. For semiconductor use, a step-down transformer is used.



Step-up



Step-down

- B. Transformers provide isolation between the primary and secondary.
- C. Transformers have manufacturer-specified voltage output and maximum current values.

III. Types of transformers

- A. Voltage transformer--step-down unit used to reduce high voltage by a specified ratio
- B. Current transformer--step-down transformer used to reduce high current and provide isolation from high voltages; provides a fraction of current to gauge value of total current
- C. Air-core transformer--one without an iron or metal core; usually applied to low-power, high-frequency uses
- D. Autotransformer--primary and secondary windings are of a common core and share a common connection

  WARNING: This transformer does not have an isolated secondary.
- E. Iron-core transformer--one that has a metal core usually made of laminations of iron or steel; usually applied to low-frequency, high-power applications
- F. Toroidal transformer--has a ring-shaped core around which windings are wrapped

G. Isolation transformer--used to isolate circuits from a common ground, from direct-current potentials or to improve power transfer by impedance-matching improvement, often providing no voltage change

WARNING: An isolation transformer should be used between test equipment to avoid possible electrical shock.

H. Variable AC transformer (Variac)--can be varied while in operation

WARNING: This transformer does not have an isolated secondary.

I. Step-down transformer--used to reduce voltage while increasing current capability above that of the source

J. Step-up transformer--used to increase voltage while decreasing the source's current capability

NOTE: Because of energy conservation laws, step-up and step-down transformers always decrease current for voltage or vise versa, as measured from the primary to the secondary.

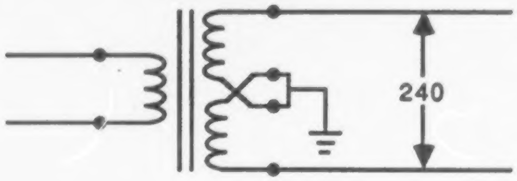
K. Spark coil--high-voltage transformer, usually an autotransformer; often used to develop high-voltage ignition for gasoline engines and gas-firing devices

L. Booster transformer--additional transformer placed in a transmission or distribution line to boost voltage to an acceptable level from a reduced level caused by line length

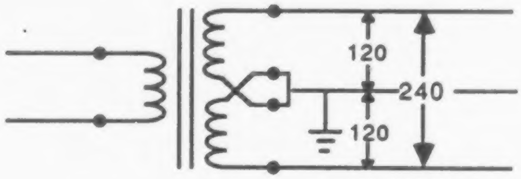
IV. Types of single-phase transformer connections

NOTE: Transformers shown are standard power-distribution types with two 120-volt secondary windings. A single winding or two in parallel will produce 120 volts. Both windings in series will produce 240 volts. Grounded terminals produce the "neutral conductor."

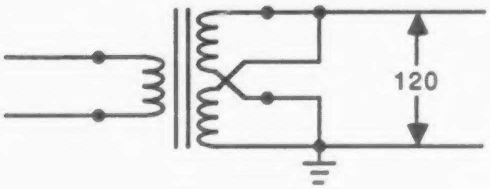
A. 240 volts, two-wire



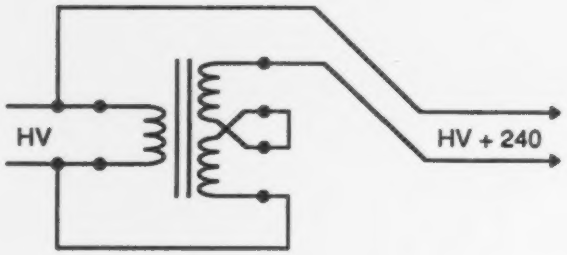
B. 120/240 volts, three-wire



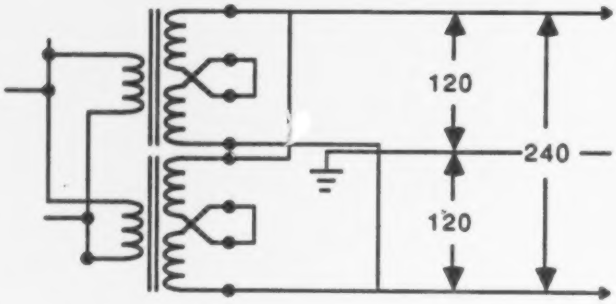
C. 120 volts, two-wire



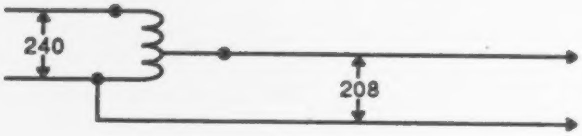
D. High voltage, boosted by 240 volts



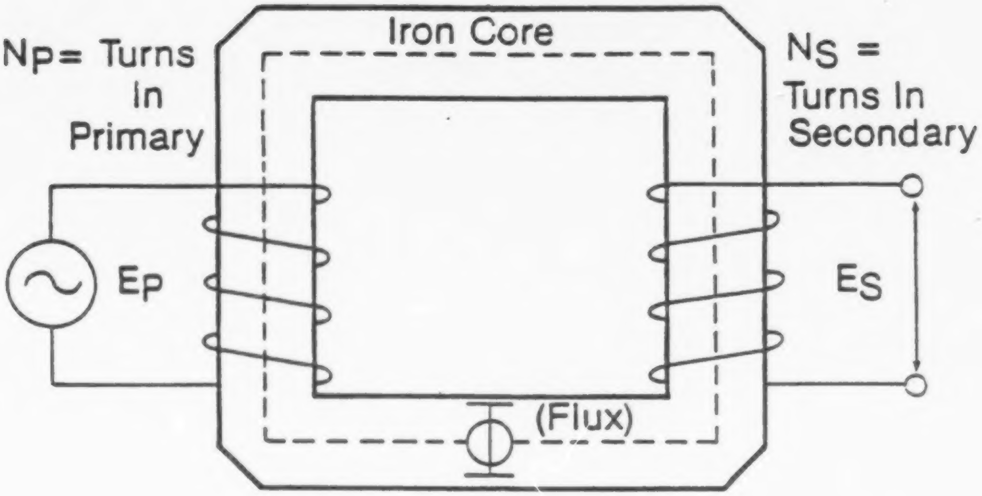
E. 120/240 volts, three-wire with additional power capacity of two transformers



F. 208 volts, two-wire from 240 volt through autotransformer

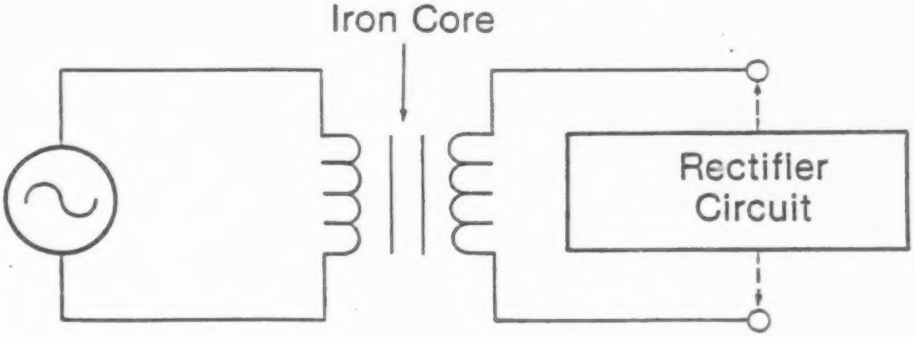


THE TRANSFORMER


Iron Core
N_P= Turns In Primary
N_S = Turns In Secondary
E_P
E_S
Φ (Flux)

Pictorial Representation

$$\frac{E_S}{E_P} = \frac{N_S}{N_P} \qquad E_S = E_P \frac{N_S}{N_P}$$


Iron Core
Rectifier Circuit

Schematic

JS 1.1

DETERMINE TRANSFORMER CONFIGURATION

Equipment:

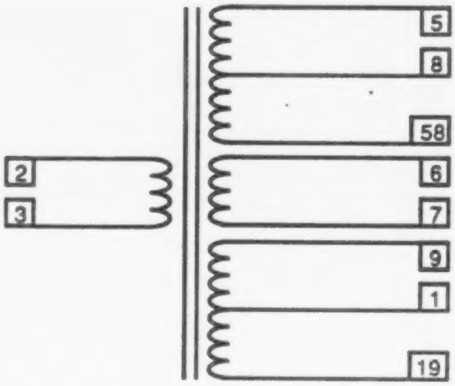
Multimeter
Voltmeter
DC power supply or DC source (battery), 12-24 volts with test leads
Variable AC supply, 60 Hz, 20-120 volts with test leads
Multiple-winding transformer with diagram, 60 Hz, 120- to 240-volt primary, step-down secondaries, wire leads attached
Wire markers (numbered tape markers), at least half as many as the number of transformer connections

Procedure: Evaluation 3 2 1 N

1. Use wire markers to mark each transformer lead wire. ___ ___ ___ ___

   NOTE: Use a number "2" and a number "10" to make 210, etc. Each wire should have a different number or a different pair of numbers.

2. Use the ohmmeter to identify which wires are interconnected. Record the numbers in groups as shown below. ___ ___ ___ ___



3. Connect the transformer to the AC supply or Variac by connecting it to the group that has only one pair, the heaviest insulation, is color-coded black or is the most removed from the other leads. ___ ___ ___ ___

   NOTE: This should be the primary input. Ask the instructor to check your work before proceeding to the next step. The number '58' indicates a possible connection to wire #5 or #8.

4. Separate wires so that the leads do not touch. Turn the AC supply output control down to the minimum. ___ ___ ___ ___

5. Turn on the power, adjusting the AC supply output for 20 volts. Use the voltmeter if the supply does not have a panel meter. ___ ___ ___ ___

6. Use voltmeter to measure between wires within each group. If any pair produces a reading of more than 20 volts, reconnect the power supply to that pair.

7. Remeasure and record the voltage between each pair with each group as shown in the preceding figure.

8. Sketch each group from voltage readings.

NOTE: The two having the highest readings are the outside ends of the windings; other measurements should be parts of that total voltage.

9. Disconnect the AC supply. Connect one primary lead to the DC supply.

10. Answer the following questions.

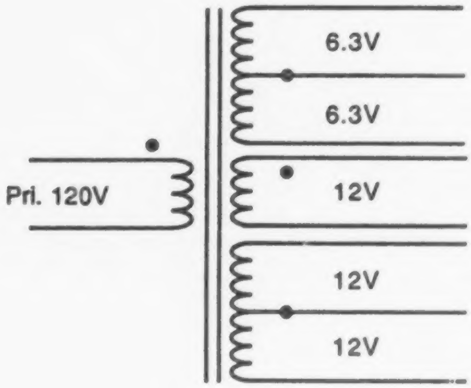
    a. Do transformers operate on DC power? __________

    b. If AC is constantly changing, is it significant to assign a polarity relationship to transformer windings? _________

11. Connect the voltmeter between a pair of leads representing the ends of a winding. Set controls for 24-volts DC.

12. Making contact for only a split-second while watching the voltmeter, turn on the DC supply and briefly touch the remaining transformer primary lead to the other DC supply output terminal.

13. If the voltmeter deflects toward upper scale (positive flash for digital meters), return to the sketches made in Step 8. Draw in, marking the transformer lead connected to the positive voltmeter lead with a large dot next to the number, as shown in the figure that follows.



NOTE: These dots are called phasing dots and are sometimes seen on schematics.

14. If the meter indication tends to go negative or off scale, use the Step 8 sketches to draw and mark the transformer lead connected to the negative voltmeter lead with a large dot. ____ ____ ____ ____

15. Continue with Steps 12, 13 and 14 for each set of secondary end leads. ____ ____ ____ ____

16. Using the Step 8 sketches, draw in the transformer primary. Mark a large dot next to the lead connected to the positive terminal of the DC supply. ____ ____ ____ ____

17. Redo the sketch of the transformer, making all dot-marked leads at the top of the windings as in the preceding figure. ____ ____ ____ ____

18. Multiply each AC voltage reading by six (since the input was only 20 volts in the test, or 1/6 of 120 volts). ____ ____ ____ ____

NOTE: If the transformer has a 240-volt primary, multiply each voltage reading by 12.

19. Record the voltages on the new transformer sketch. Show your sketch to the instructor. ____ ____ ____ ____

20. Return equipment and materials to the proper storage area. ____ ____ ____ ____

Average of above evaluations* ____ ____ ____ ____

*This average is the student's partial evaluation for competency C2: Determine transformer requirements.

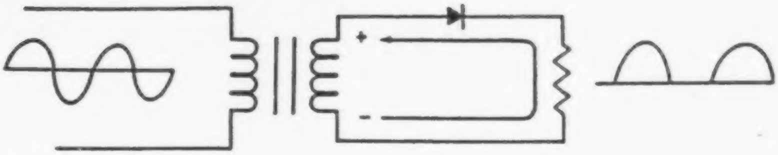
MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT IV: UNREGULATED POWER SUPPLIES

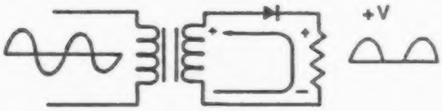
LESSON 2: RECTIFIERS

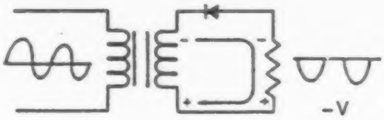
I. Half-wave rectifier

- A. Half-wave rectifier circuits convert AC voltage to pulsating DC voltage.



- B. Characteristics
    1. Does not require a transformer
    2. Uses one diode
    3. Allows current to flow in one direction through the load
    4. Uses only one half of the input waveform
    5. Input and output frequency are the same.
    6. May produce positive or negative voltage with respect to ground



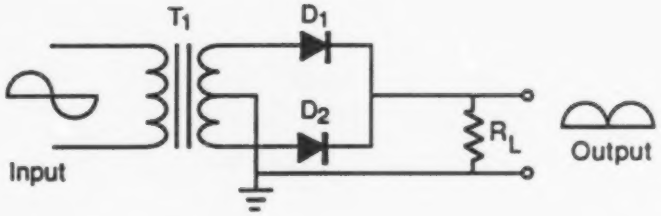


- C. Voltage output formulas
    1. $E_{rms} = E_{peak} \times 0.707$
    2. $E_{peak} = E_{rms} \times 1.414$
    3. $E_{avg} = E_{peak} \times 0.318$
    4. $PIV = 2 \times E_{peak}$
- D. Advantages
    1. Inexpensive
    2. Few components
    3. Small
- E. Disadvantages
    1. Low rms output
    2. Harder to filter

II. **Full-wave rectifier (TM 2.1)**

A. Full-wave rectifier circuits convert AC voltage to pulsating DC voltage.

B. The full-wave rectifier requires two diodes and a center-tapped transformer.

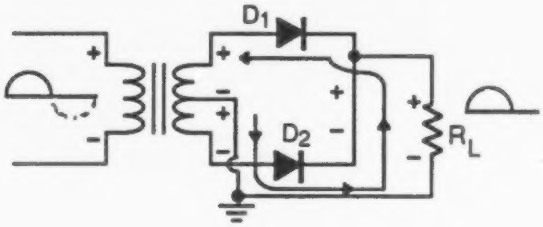


C. When the center tap of the transformer is grounded, voltages at points A and B are 180° out of phase with each other.

   1. On the positive alternation of the input sine wave, point A is positive, with respect to ground, and point B is negative.

      a. D_1 is forward-biased and D_2 is reverse-biased.

      b. Current flows in the direction indicated, producing a positive output.

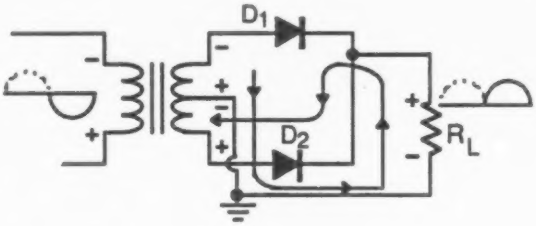


   2. During the negative alternation of the input sine wave, point A is negative and point B is positive.

      a. D_1 is reverse-biased and D_2 is forward-biased.

      b. Current flows in the direction indicated, producing a positive output.

      c. Notice the direction of current flow through R_L.



   3. Current flows in the same direction through R_L for both the positive and negative alternation of the input sine wave.

D. The circuit uses the full wave and produces an output of positive voltage for both alternations of the input waveform.

E. Output frequency is twice the frequency of the input.

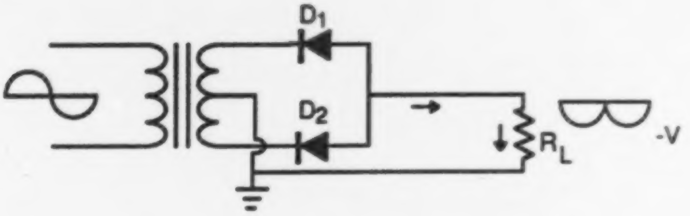
F. Voltage output formulas

   1. $E_{peak} = E_{rms} \times 1.414$

   2. $E_{rms} = E_{peak} / 1.414$

   3. $E_{avg} = E_{peak} \times 0.636$

G. To produce a negative output, the diodes can be reversed.



H. Advantages compared to the half-wave rectifier

   1. Easier to filter

   2. More efficient

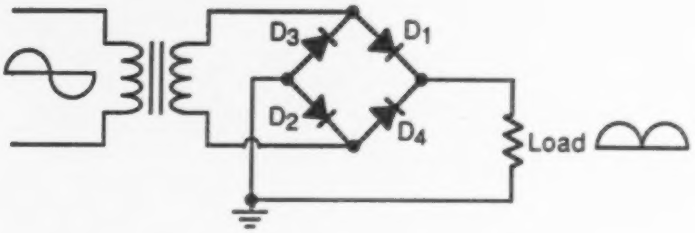
I. Disadvantages compared to the half-wave rectifier

   1. Center-tapped transformer

   2. Lower peak voltage

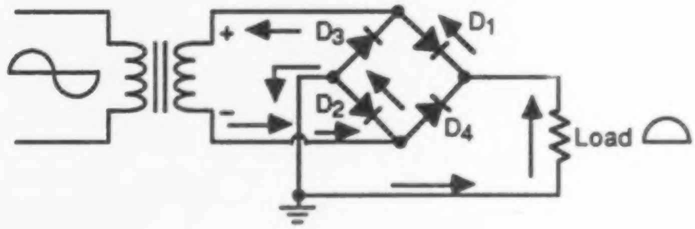
III. Bridge rectifier (TM 2.2)

   A. Bridge-rectifier circuits convert AC voltage to pulsating DC voltage.



   B. The bridge requires four diodes but does not require a transformer. (However, it is generally used with a transformer.)

   C. On the positive alternation of the input sine wave, point A is positive with respect to point B.



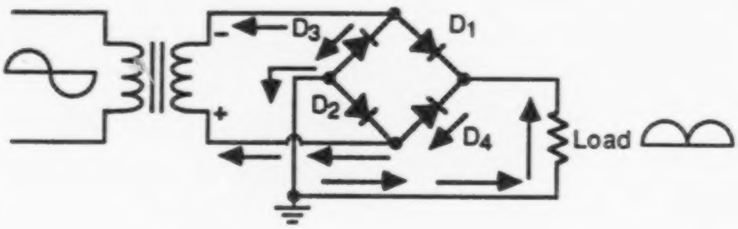
      1. D_1 and D_2 are forward-biased and D_3 and D_4 are reverse-biased.

      2. Current flows through D_1, R_L and D_2 in the direction shown, producing a positive output voltage.

D. **During the negative alternation of the input sine wave, point B is positive with respect to point A.**

1. **D_3 and D_4 are forward-biased and D_1 and D_2 are reverse-biased.**

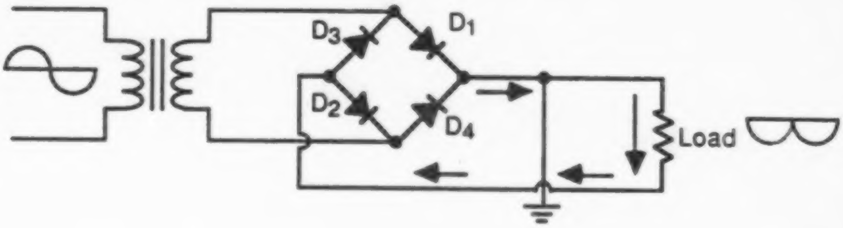
2. **Current flows through D_3, R_L and D_4 in the direction shown, producing a positive output.**



E. **The output frequency is twice the input frequency.**

F. **Current flows the same direction through R_L for both the positive and negative alternation of the input sine wave.**

G. To produce a negative output voltage, the ground connection at the junction of D_1 and D_3 can be moved to the junction of D_2 and D_4. Then, the load, R_L, is connected to the junction of D_1 and D_3.



H. Advantages compared to a full-wave circuit

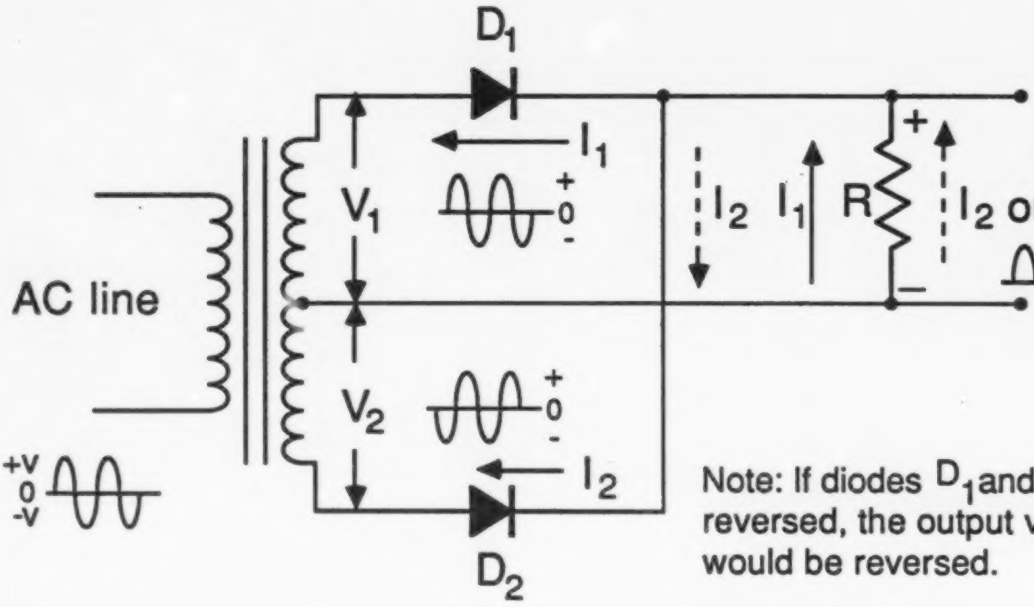
1. Transformer not required

2. Higher output voltage

I. Disadvantage compared to a full-wave circuit: four diodes (costly)

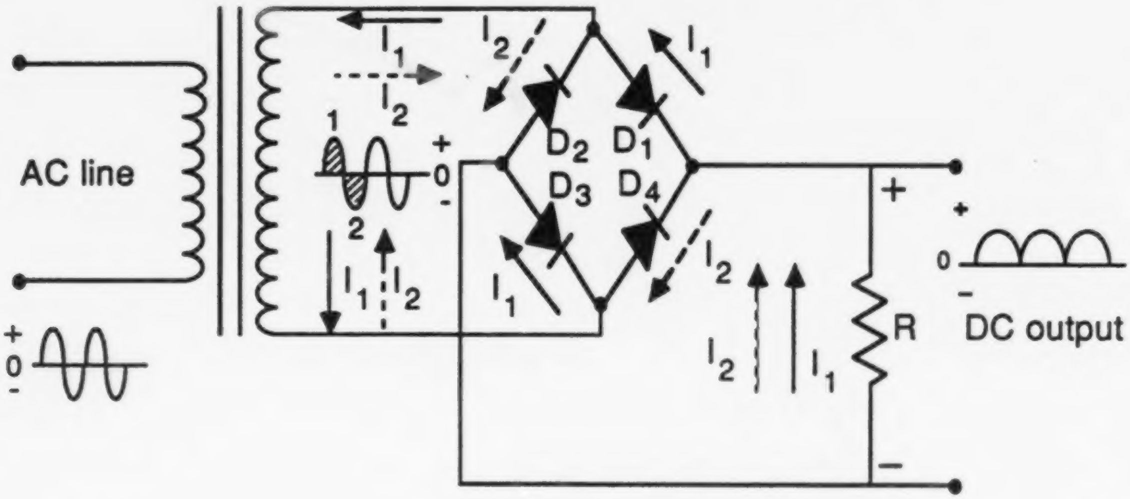
TM 2.1

CONVENTIONAL FULL-WAVE RECTIFIER


D1
I1
V1
+
0
-
I2
I1
R
+
I2
DC
output
+
0
AC line
V2
+
0
-
I2
+V
0
-V
D2

Note: If diodes D_1 and D_2 were reversed, the output voltage would be reversed.

BRIDGE RECTIFIER


AC line
+
0
-
I_1
I_2
1
2
+
0
-
I_1
I_2
D_2
D_1
D_3
D_4
I_1
I_2
I_1
I_2
I_2
I_1
+
R
−
+
0
-
DC output

Note: If each of the diodes were reversed, the output would be reversed.

CONSTRUCT AND TEST A HALF-WAVE RECTIFIER CIRCUIT

Equipment:

Low power filament transformer (120v primary, 6-24v secondary)
Silicon diode, 1N4004 or equivalent
6800Ω, 1/2w resistor
Multimeter
Oscilloscope
Graph paper

Procedure:

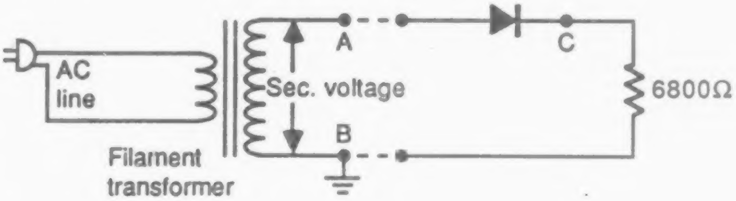
Evaluation
3 2 1 N

WARNING: Dangerous voltage levels are present during this procedure. Check with the instructor regarding safety procedures.

1. Connect the multimeter (set for AC) to the secondary of the filament transformer. _ _ _ _

2. Plug the filament transformer into the line voltage and measure the secondary voltage at points A and B. _ _ _ _

3. Turn off the power. Connect the following circuit to the secondary of the filament transformer. _ _ _ _



4. Turn the power on. Measure the voltage between points A and B and record as the AC input voltage. _ _ _ _

   ________ V_{rms}

5. Measure and record the DC output voltage with the multimeter. _ _ _ _

   ________ V_{rms}

6. Observe and make a scale drawing of the AC input voltage (A to B) and the DC output voltage (C to B). _ _ _ _

7. Calculate the average DC output voltage and compare it to the measured DC output voltage. ________ V_{DC} _ _ _ _

8. Return equipment to its proper storage area. ____ ____ ____ ____

Average of above evaluations* ____ ____ ____ ____

*This average is the student's partial evaluation for competencies C1-4, 8-9.

JS 2.2

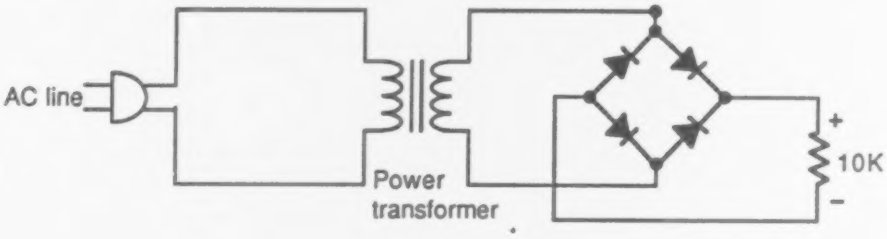
CONSTRUCT AND TEST A FULL-WAVE BRIDGE RECTIFIER CIRCUIT

Equipment:

Power transformer (110v)
Four silicon diodes 1N4004 or equivalent
10KΩ, 1w resistor
Multimeter
Oscilloscope
Graph paper

Procedure:

	Evaluation			
	3	2	1	N
WARNING: Dangerous voltage levels are present during this procedure. Avoid shock hazards.				
1. Construct the circuit shown below but do not connect power at this time. Have instructor check your circuit.	—	—	—	—



2. Connect the multimeter across the secondary of the power transformer.	—	—	—	—
3. Connect the transformer to the AC line. Read and record the DC voltage across the 10KΩ load resistor. __________ V_{DC}	—	—	—	—
4. Connect an oscilloscope across the filament transformer secondary and observe and sketch the waveform.	—	—	—	—
5. Connect an oscilloscope across the 10KΩ load resistor and observe and sketch the waveform.	—	—	—	—
6. Calculate the average DC output voltage and compare with the measured DC output voltage. __________ V_{DC}	—	—	—	—

7. Return equipment to its proper storage area. _ _ _ _

Average of above evaluations* _ _ _ _

*This average is the student's partial evaluation for C9 and final evaluation for competencies C1-4 and C8.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT IV: UNREGULATED POWER SUPPLIES

UNIT TEST

Match types of transformers on the right with the descriptions on the left.

____ 1. Step-down unit used to reduce high voltage by a specified ratio

____ 2. Used to reduce high current and provide isolation from high voltages; provides a fraction of current to gauge total current

____ 3. Without an iron or metal core; usually applied to low-power, high-frequency applications

____ 4. Primary and secondary windings are of a common core and share a common connection; does not have an isolated secondary

____ 5. Has a metal core usually made of laminations of iron or steel; usually applied to low-frequency, high-power applications

____ 6. Has a ring-shaped core around which windings are wrapped

____ 7. Should be used between test equipment to avoid possible electrical shock

____ 8. Can be varied while in operation; does not have an isolated secondary

____ 9. Used to increase voltage while decreasing the source's current capability

____ 10. High-voltage transformer, usually an autotransformer; often used to develop high-voltage ignition for gasoline engines and gas-firing devices

a. Air-core

b. Autotransformer

c. Booster

d. Current

e. Iron-core

ab. Isolation

ac. Spark coil

ad. Step-down

ae. Step-up

bc. Toroidal

bd. Variac

be. Voltage

Mark "a" if the statement is true and "b" is the statement is false.

____ 11. Rectification is changing AC to DC.

____ 12. Diodes make good rectifiers.

____ 13. A transformer that has 120 V_{AC} across its primary and 40 V_{AC} across its secondary is a step-up transformer.

____ 14. The positive end of the load will be in contact with the anode of the rectifier.

____ 15. A single diode can give full-wave rectifications.

____ 16. A bridge rectifier can eliminate the need for a center-tapped transformer.

____ 17. A bridge rectifier uses four diodes.

____ 18. A half-wave rectifier uses a center-tapped transformer.

____ 19. The transformer is a device used to either step-up (increase in amplitude) or step-down the AC voltage input to a rectifier circuit.

____ 20. When voltage is stepped-up from primary to secondary, the current is stepped-up at the same ratio.

____ 21. The phase relationship between primary and secondary voltage is dependent upon the method of construction and the direction of the windings.

____ 22. The transformer is used to provide isolation of the equipment and circuit from the power line.

____ 23. A transformer may be used to provide multiple voltages to a number of rectifier circuits.

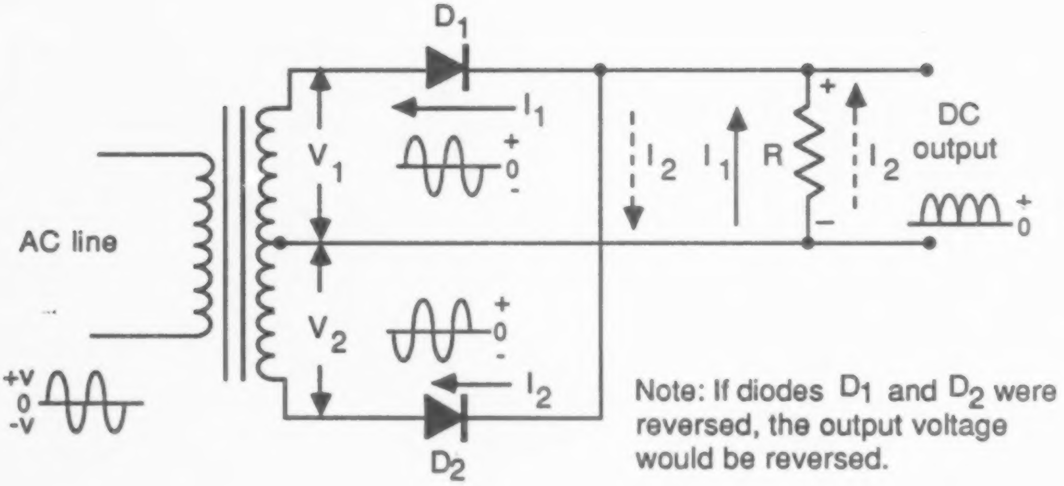
24. Draw the schematic diagram of a full-wave rectifier circuit.

25. Draw the schematic diagram of a bridge rectifier circuit.

ANSWERS TO UNIT TEST

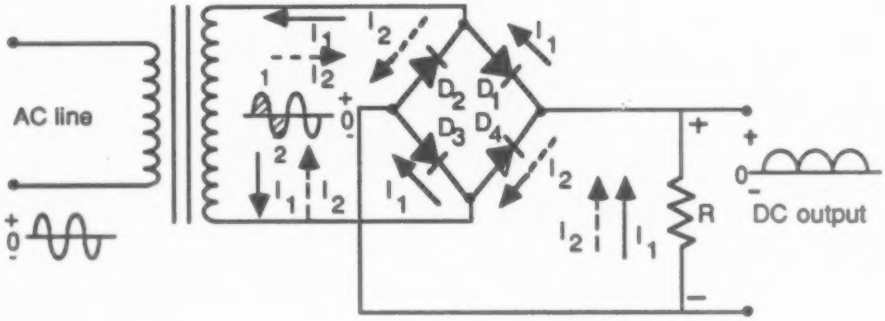
1. be (C1)
2. d (C1)
3. a (C1)
4. b (C1)
5. e (C1)
6. bc (C1)
7. ab (C1)
8. bd (C1)
9. ae (C1)
10. ac (C1)
11. a (C3)
12. a (C3)
13. b (C1)
14. b (C3)
15. b (C3)
16. a (C2, C3)
17. a (C3)
18. b (C2, C3)
19. a (C1)
20. b (C2)
21. a (C2)
22. a (C1)
23. a (C1)

24.


D$_1$
I$_1$
V$_1$
+
0
-
I$_2$
I$_1$
R
I$_2$
+
–
DC
output
+
0
AC line
V$_2$
+
0
-
I$_2$
+V
0
-V
D$_2$

Note: If diodes D$_1$ and D$_2$ were reversed, the output voltage would be reversed.

25.


AC line
+
0
-
I1
I2
1
2
+
0
-
D2
D1
D3
D4
I1
I2
I1
I2
I2
I1
+
-
R
+
0
-
DC output

NOTE: If each of the diodes were reversed, the output would be reversed.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT V: POWER-SUPPLY FILTERS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to discuss the operation, use and types of power-supply filters. This knowledge will be evidenced by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Match terms about filters with definitions.

1.2 Identify true statements about power-supply filter uses and types.

1.3 Identify and describe capacitive-input filters. (competency B19)

1.4 Calculate the percent ripple and minimum-sized capacitor to be used as a filter in a power-supply circuit.

1.5 Identify and describe RC filters. (competency B18)

1.6 Identify and describe inductive-input filters.

1.7 Describe voltage multiplier circuits. (competency B19)

1.8 Construct and test a voltage doubler circuit. (partial B18-20, JS 1.1)

1.9 Construct and test a capacitor-filter circuit. (partial B18-20, JS 1.2)

1.10 Construct and test a pi-section filter circuit. (competency B18-20, JS 1.3)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT V: POWER-SUPPLY FILTERS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

   1. Lesson 1: POWER-SUPPLY FILTERS

      a. Information outline

      b. Transparency masters

         TM 1.1: Basic filter configurations
         TM 1.2: Half-wave voltage doubler circuit
         TM 1.3: Full-wave voltage doubler circuit
         TM 1.4: Voltage tripler

      c. Job sheets

         JS 1.1: Construct and test a voltage-doubler circuit
         JS 1.2: Construct and test a capacitor-filter circuit
         JS 1.3: Construct and test a pi-section filter circuit

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Grob, Bernard. Basic Electronics. 5th ed. New York: McGraw-Hill, 1984.

2. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.

3. Hughes, Fredrick W. Basic Electronics: Theory and Experimentation. Englewood Cliffs, N.J.: Prentice-Hall, 1984.

4. Malvino, Albert Paul. Semiconductor Circuit Approximations. 4th ed. New York: McGraw-Hill Book Co., 1985.

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B. Curriculum guides

1. Hartman, Lonnie. Basic Electronics. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.
2. Vorderstrasse, Ron. General Electronics Technician. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT V: POWER-SUPPLY FILTERS

LESSON 1: POWER-SUPPLY FILTERS

I. Terms and definitions

  A. Filters--used to remove ripple and produce a smooth DC current

  B. Choke--inductor

  C. Percent of ripple--way of measuring filtering efficiency

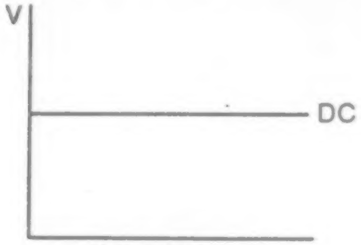
  D. Pi filter--one which looks like the Greek letter, pi (π)

II. Uses and types

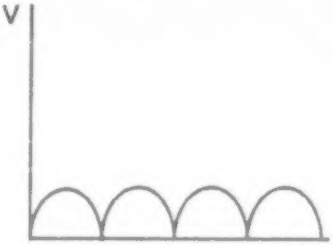
  A. Pulsating DC (ripple) from a rectifier circuit is unacceptable as power for most electronic circuits.

    1. The output ripple voltage must be smoothed out or filtered.

    2. If the ripple is filtered completely, the output voltage is pure DC.



Pure DC



    3. A source of pure DC is a battery.

  B. Main categories of power-supply filters

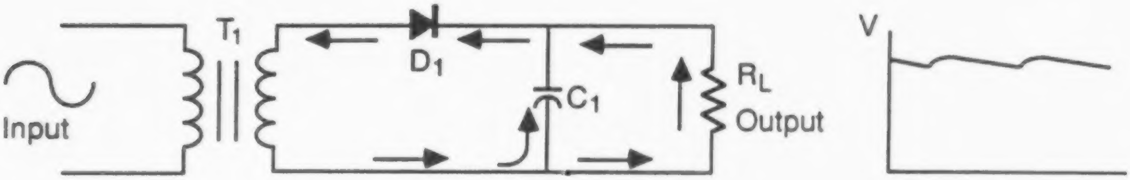
    1. Capacitive input

    2. Inductive input

III. Capacitive-input filter (TM 1.1)

  A. Operation

    1. A capacitor (which stores energy), added to the output of the rectifier circuit, charges while the diode is conducting.



2. The capacitor discharges when the output is dropping and furnishes the load current.
3. The capacitor maintains the current through the load and the voltage across the load.

B. Capacitor filters rely on three main factors.

1. Size of capacitor
2. Size of the load
3. Time between pulsations

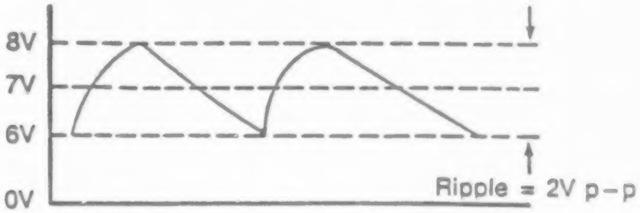
C. T = R x C (T = time; R = resistor value; C = capacitance value)

1. The longer the time between peaks, the more the capacitor discharges.
2. The more the capacitor discharges, the larger the ripple.

IV. Percent of ripple

A. Equation

$$\%\ \text{ripple} = \frac{\text{rms of ripple}}{\text{E ave.}} \times 100$$



B. rms value of the ripple:

$$E_{rms} = \text{peak} \times 0.707$$

C. To decrease the amount of ripple, use a larger capacitor.

1. Determine the size of capacitor.

$$C_{min} = \frac{1}{2.828 \times K \times R \times f}$$

K = percent of ripple in decimal form
R = load resistance in ohms
f = frequency of ripple in hertz
C_{min} = minimum capacitance in farads

2. If the calculated value of C_{min} is an unavailable value, use the next larger size of capacitor.

D. As the percentage of ripple of decreases, ripple in the output voltage decreases.

E. Adding a capacitor to a rectifier's output causes the capacitor to hold the peak voltage across the load throughout the cycle.

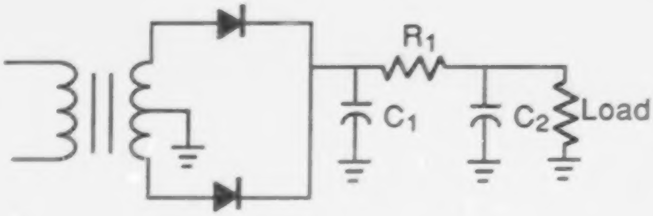
F. Both diode and capacitor must have a sufficient voltage rating to handle these values.

V. RC filters

A. The single-capacitor filter may need to be very large to handle changing current requirements of the load.

B. Another capacitor and resistor can be added to form an RC filter.

C. The RC filter works as well as the single-capacitor filter with smaller capacitors and better handles the changing load requirements.



1. C_1 filters the ripple to a low value.

2. R_1 and C_2 reduces the ripple even more.

3. R_1's value is small compared to R_{load}'s value.

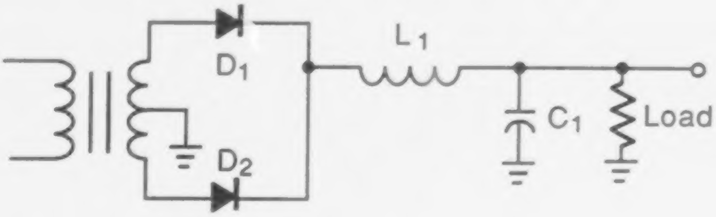
4. The RC network acts like a voltage divider to the ripple.

5. Most of the remaining ripple from C_1 is dropped across R_1.

6. The drop across R_1 takes a small, acceptable amount of voltage away from the load.

VI. Inductive-input filters

A. The inductive filter uses an inductor and a capacitor.



B. The inductor (L) and the capacitor (C) work together to provide a purer DC than the single-capacitor filter.

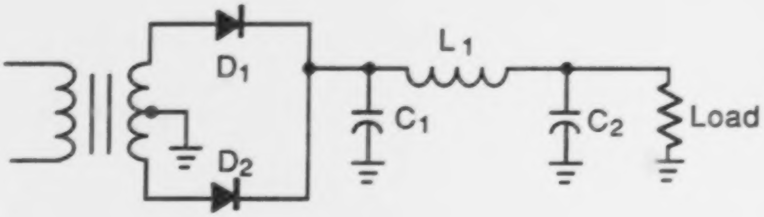
C. The choke/inductor (L) has a high reactance to the ripple frequency but little effect on DC voltage.

D. LC filters are made by adding another capacitor to the circuit.

1. C_1 filters the ripple to a low level.

2. L_1 and C_2 form an AC-voltage divider that filters the ripple further with little effect on DC voltage.

E. LC filter characteristics



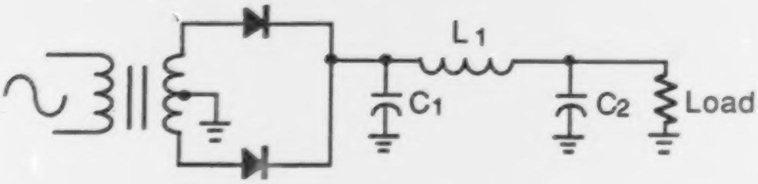
1. Removes ripple with a DC voltage loss to the load

2. Large, heavy and expensive

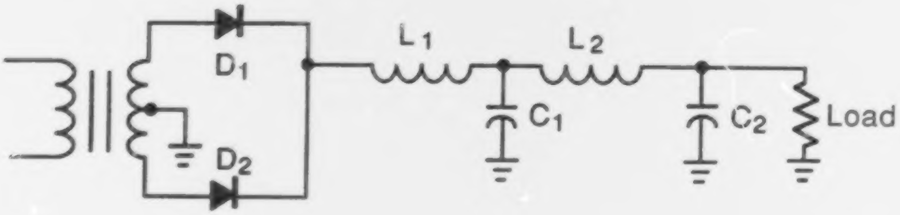
3. Filters ripple very well and does not allow the load voltage to change, unlike the RC filter

F. Pi filter (another type of LC filter) **(TM 1.1)**

1. Has a high voltage output but changes rapidly as load current increases



2. Disadvantages can be overcome by adding a second choke.

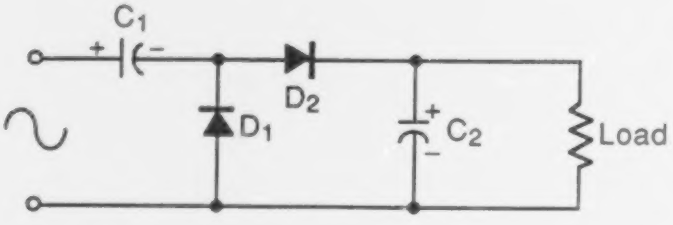


a. Circuit provides a more stable output but is large, heavy and expensive.

b. Pi filters are used in high-power circuits.

VII. Voltage multipliers

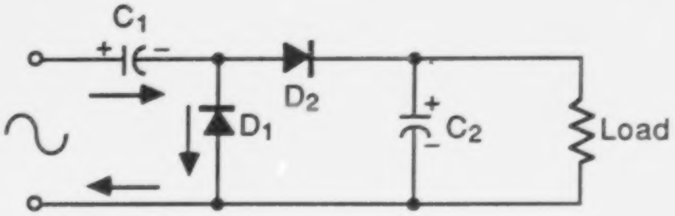
A. The half-wave voltage doubler produces a DC voltage that is twice the peak value of the AC input. **(TM 1.2)**



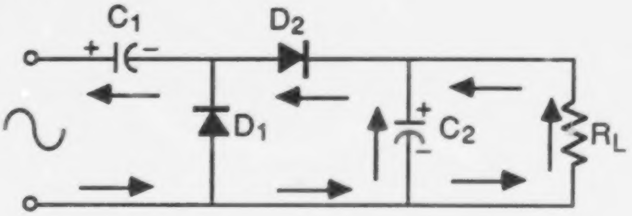
1. The circuit is hard to filter; the output capacitor must have a voltage rating that is twice the peak value of AC input.

2. On the negative alternation, C_1 charges to peak.

3. On the positive alternation, C_1 adds to the positive AC input and charges C_2 to twice the peak voltage.

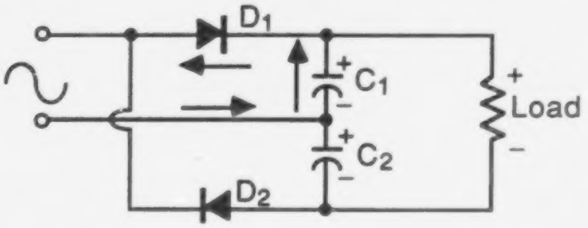


4. R_L is in parallel with C_2, and the voltage appears across R_L.

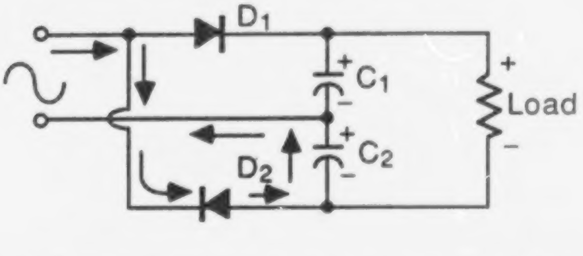


B. A full-wave voltage doubler can double the output voltage of a full-wave rectifier. (TM 1.3)

1. On the positive alternation of the AC input, C_1 charges through D_1 to the AC input's peak value.

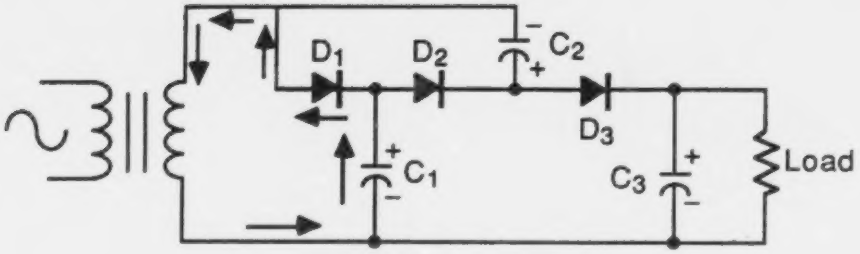


2. On the negative alternation of the AC input, C_2 charges through D_2 to the AC input's peak value.

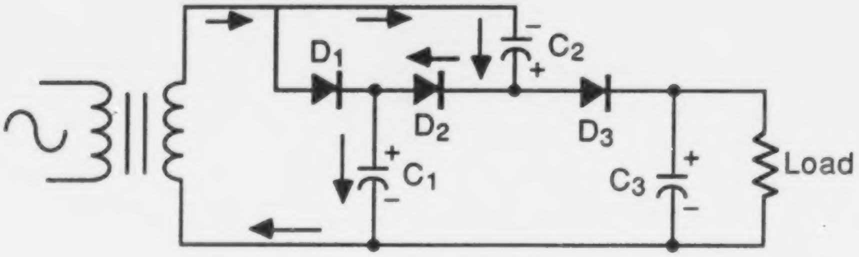


3. With C_1 and C_2 both charged to peak, voltage across R_L is twice the peak input voltage.

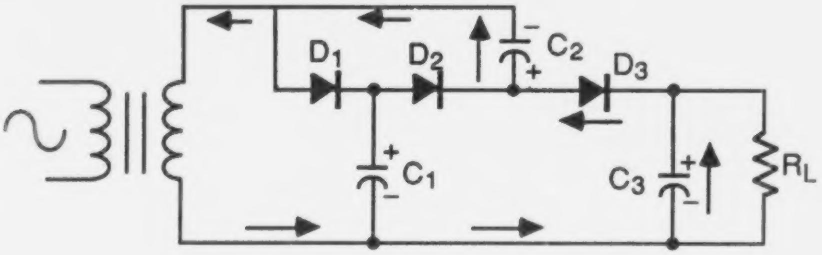
C. Voltage triplers produce an output three times that of AC peak input. (TM 1.4)



1. On the first positive alternation of the AC input, C_1 charges to peak through D_1.

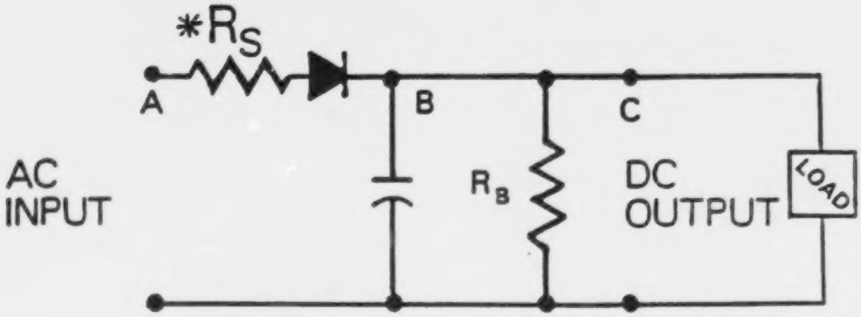


2. During the negative alternation of the AC input, C_2 charges to the negative peak value plus the peak value of C_1.



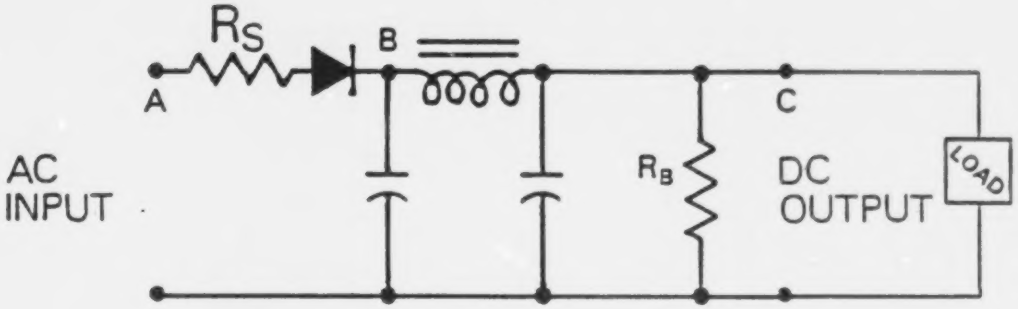
3. At the peak of the next positive alternation of the AC input, C_3 charges to peak plus twice the peak charge of C_2.
4. C_3 is charged to three-times peak; with R_L in parallel with C_3, the voltage appears across R_L.
5. By adding more stages to this circuit, higher voltage multipliers can be constructed.

BASIC FILTER CONFIGURATIONS

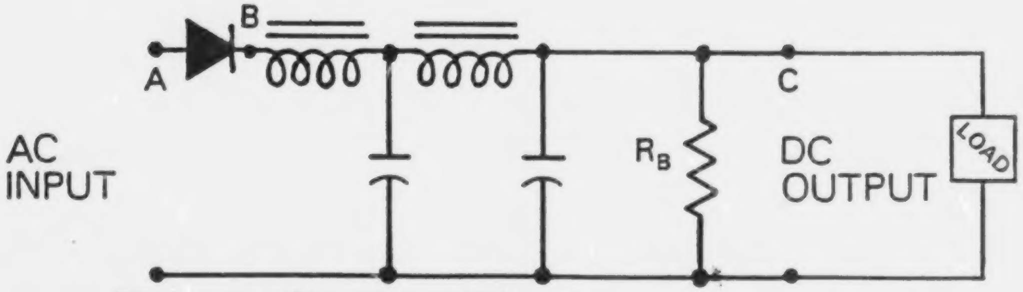

*R_S
A
B
C
AC INPUT
R_B
DC OUTPUT
LOAD

Capacitor Filter

NOTE- Capacitor must be removed to observe rectifier output waveform.


R_S
A
B
C
AC INPUT
R_B
DC OUTPUT
LOAD

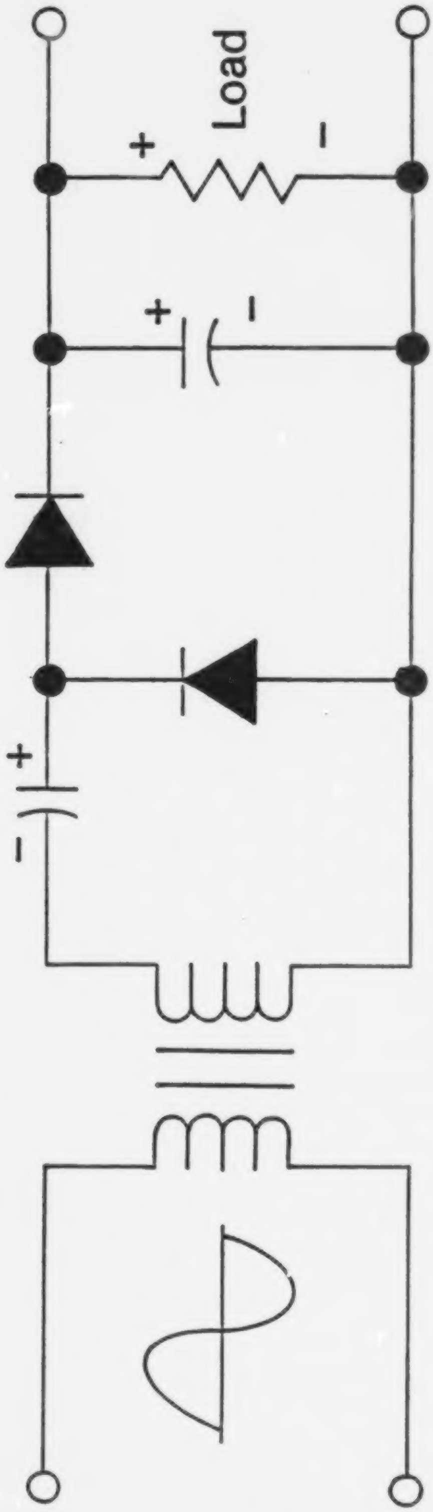
Pi-Section Filter


A
B
C
AC INPUT
R_B
DC OUTPUT
LOAD

Two L-Section Filter

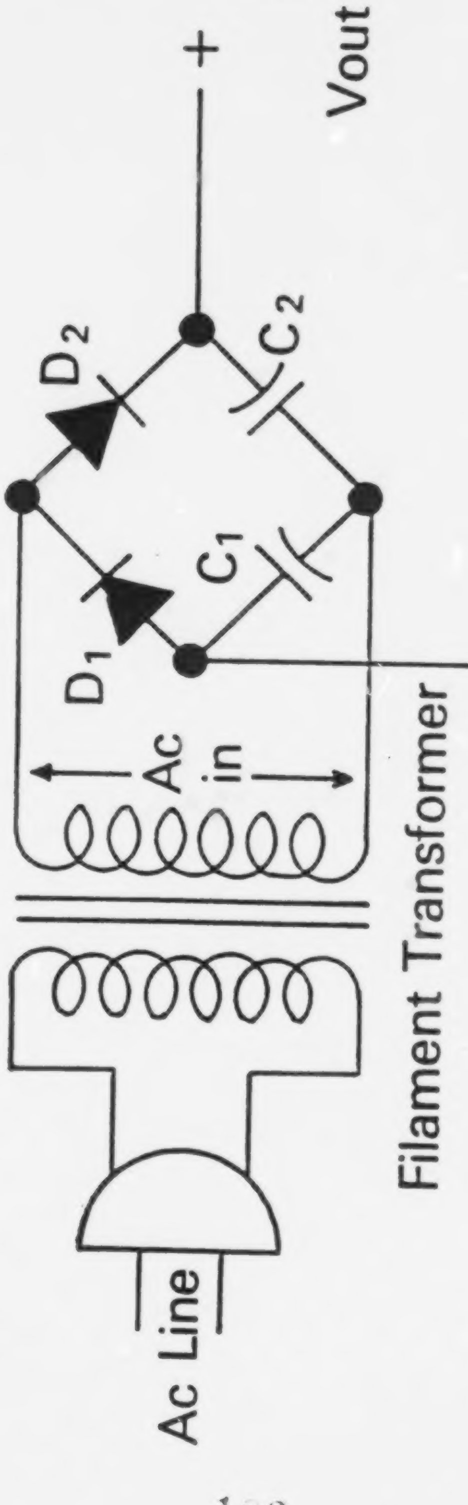
* NOTE- R_S in series with diode limits initial surge of current due to capacitor and is called a surge resistor.

HALF-WAVE VOLTAGE DOUBLER CIRCUIT

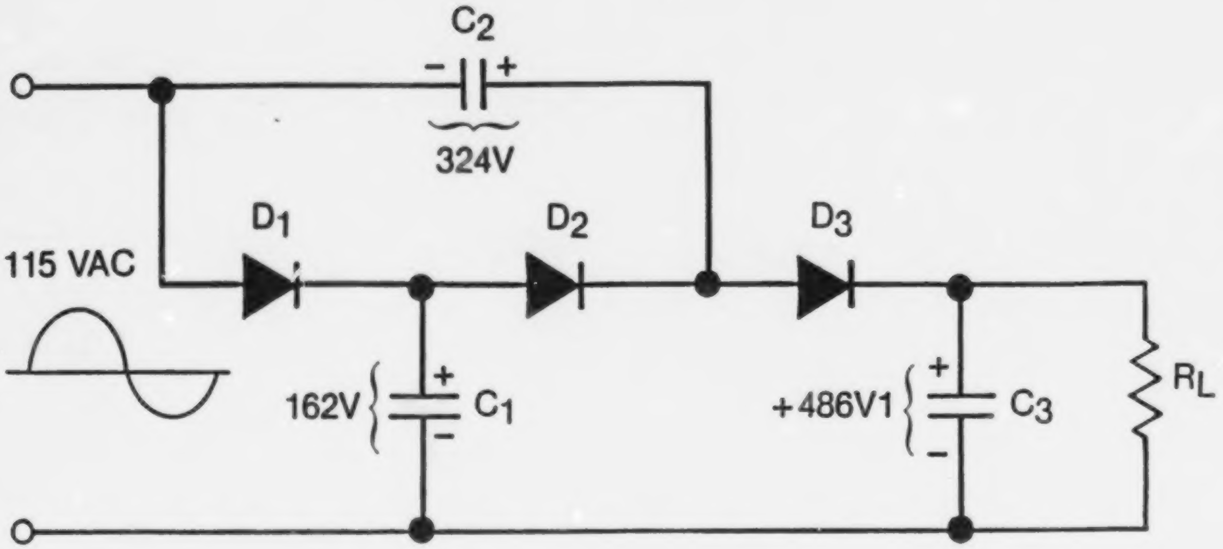


TM 1.3

FULL-WAVE VOLTAGE DOUBLER CIRCUIT


+
Vout
−
D₂
C₂
D₁
C₁
Ac in
Filament Transformer
Ac Line

VOLTAGE TRIPLER


C2
−
+
324V
D1
D2
D3
115 VAC
162V
+
−
C1
+486V1
+
−
C3
RL

CONSTRUCT AND TEST A VOLTAGE-DOUBLER CIRCUIT

Equipment:

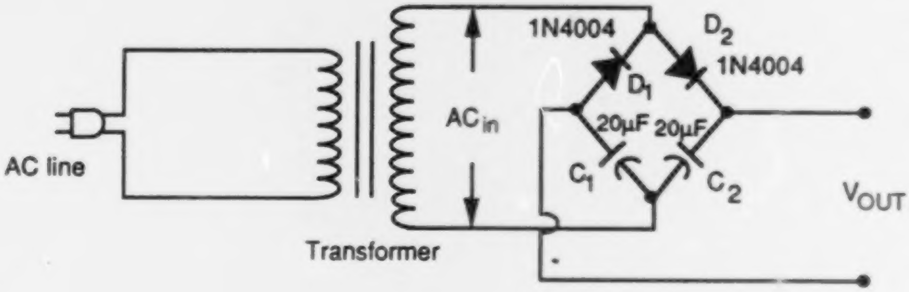
Low-power transformer (120v primary, 6-24v secondary)
Two silicon diodes, 1N4004 or equivalent
Two 20μF capacitors, 450V
Multimeter
Oscilloscope

Evaluation
3 2 1 N

Procedure:

WARNING: Dangerous voltage levels are present during this procedure. Avoid shock hazards.

1. Connect the following circuit but do not connect the filament transformer to the AC line. Ask the instructor to check your wiring. _ _ _ _

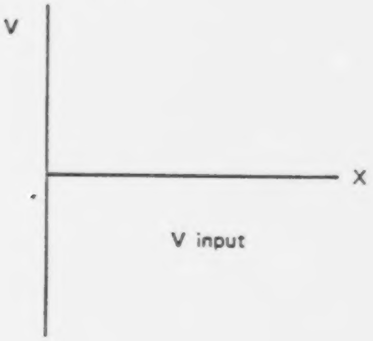


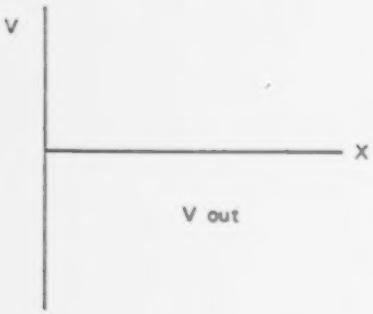
2. Plug in the filament transformer. Measure and record voltage across C_1, C_2, the output and the secondary winding of the filament transformer. _ _ _ _

V_{c1} = ____________

V_{c2} = ____________

$V_{secondary}$ = ______





3. Using an oscilloscope, observe and measure the input and output voltages of the rectifier circuit and sketch the waveforms. ___ ___ ___ ___

4. Return equipment to its proper storage area. ___ ___ ___ ___

Average of above evaluations* ___ ___ ___ ___

*This average is the student's partial evaluation for competencies B18-20.

CONSTRUCT AND TEST A CAPACITOR-FILTER CIRCUIT

Equipment:

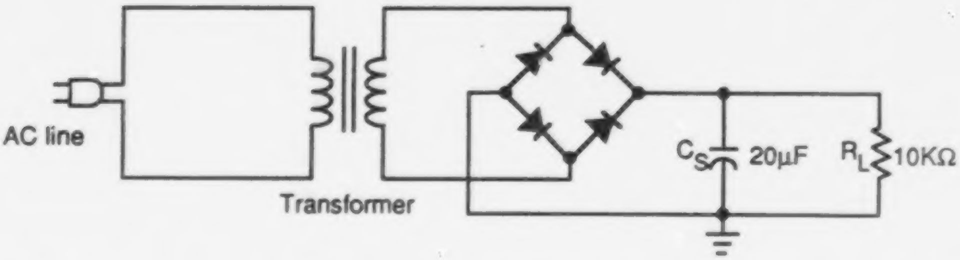
Low-power transformer (120V primary)
Four silicon diodes, 1N4004 or equivalent
One 10KΩ, .5W resistor; one 1KΩ, .5W resistor; one 20μF capacitor, 25W V_{DC} or greater
Multimeter
Oscilloscope
Graph paper

Procedure:	Evaluation 3	2	1	N

WARNING: Dangerous voltage levels are present during this procedure. Avoid shock hazards.

1. Construct the circuit shown below but do not connect power at this time. Ask the instructor to check your circuit. — — — —

   NOTE: Do not connect the capacitor at points A and B at this time.



2. Connect the multimeter across the secondary of the filament transformer and record the voltage. — — — —
3. Read and record DC voltage across the load resistor. — — — —
4. Connect an oscilloscope across the load resistor; observe and sketch the waveform. Turn off the power. — — — —
5. Connect the 20μF capacitor at points A and B. — — — —
6. Turn the power on. Repeat steps 3 and 4. — — — —
7. Replace the 10KΩ load resistor with the 1KΩ load resistor and repeat steps 3 through 6. — — — —
8. Compare the wave shapes and DC voltage levels of the filter and a 10K load resistor with the filter and a 1KΩ load resistor. — — — —

9. Using the output voltage measured with the 10KΩ load resistor as no-load voltage and the output voltage measured with the 1KΩ resistor as full-load, compute percent voltage regulation in the table below. _ _ _ _

Data	$V_{sec.}$	$V_{10K\Omega}$	$V_{1K\Omega}$	% Reg.
No filter				
With filter				

10. Return equipment to its proper storage area. _ _ _ _

Average of above evaluations* _ _ _ _

*This average is the student's partial evaluation for competencies B18-20.

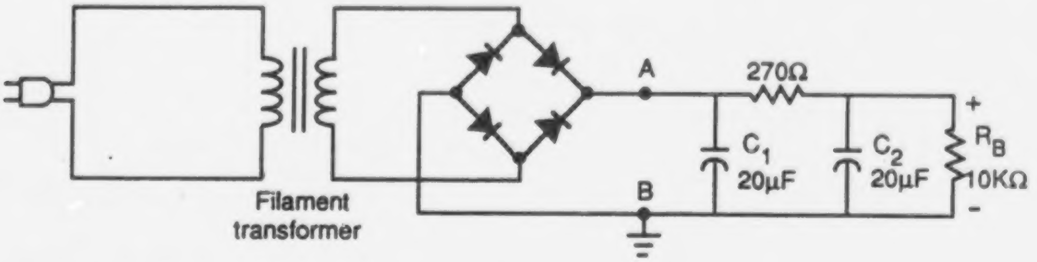
CONSTRUCT AND TEST A PI-SECTION FILTER CIRCUIT

Equipment:

Low-power filament transformer (120v primary)
Four silicon diodes, 1N4004 or equivalent
10K, .5w resistor
1KΩ, .5w resistor
Two 20µF capacitors, 25W V_{DC} or great
Multimeter
Oscilloscope
Graph paper
270Ω resistor

Procedure:	Evaluation 3	2	1	N
1. Connect the circuit shown below but do not apply power at this time. Ask the instructor to check your circuit.	___	___	___	___

NOTE: Do not connect the pi-section filter network at point A and B at this time.



2. Connect the multimeter across the secondary of the filament transformer.	___	___	___	___
3. Read and record DC voltage across the load resistor.	___	___	___	___
4. Connect an oscilloscope across the load resistor; observe and sketch the waveform. Turn off the power.	___	___	___	___
5. Connect the pi-section at points A and B. Turn on the power and repeat steps 3 and 4.	___	___	___	___
6. Replace the 10KΩ load resistor with a 1KΩ load resistor and repeat steps 3, 4 and 5.	___	___	___	___
7. Compare wave shapes and DC voltage levels of the pi-section filter and the 10K load resistor with the pi-section filter and the 1KΩ resistor.	___	___	___	___

8. Using the output voltage measured with the 10KΩ load resistor as no-load voltage and the output voltage measured with the 1KΩ resistor as full-load, compute percent voltage regulation in the table below. ___ ___ ___ ___

Data	$V_{10K\Omega}$	$V_{1K\Omega}$	% Reg.
No filter			
With filter			

9. Return equipment to its proper storage area. ___ ___ ___ ___

Average of above evaluations* ___ ___ ___ ___

*This average completes the student's evaluation for competencies B18-20.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT V: POWER-SUPPLY FILTERS

UNIT TEST

Choose the option which best answers the question or completes the statement.

___ 1. Which voltage do power supply capacitors attempt to keep constant? How is this accomplished?

a. DC output, charging through the load resistor
b. AC output, charging through the load resistor
c. Ripple output, charging through the load resistor
d. AC input, charging through the load resistor
e. Ripple output, monitoring the battery

___ 2. Which is easiest to filter?

a. Half-wave rectification
b. Bridge rectification
c. AC
d. Step-up rectification
e. None of the above

___ 3. How does the ripple voltage for a full-wave power supply compare with that for a half-wave power supply?

a. Less than
b. Equal to
c. More than
d. Does not apply
e. Opposite direction

___ 4. What kind of filter uses a resistor and a capacitor?

a. CL
b. AB
c. RC
d. DC
e. AC

___ 5. What kind of DC voltage is produced by a half-wave voltage doubler?

a. Half the rms value
b. Twice the rms value
c. Half the peak voltage
d. Double the peak voltage
e. Triple the peak voltage

____ 6. What is an inductor also called?

a. Choke
b. Resistor
c. Capacitor
d. PI
e. None of the above

____ 7. What is pulsating DC also called?

a. Ripple
b. AC
c. PI
d. Pure DC
e. None of the above

____ 8. What happens when the percent of ripple increases?

a. Less ripple in the output voltage
b. More ripple in the output voltage
c. Diodes increase in the circuit
d. Diodes decrease in the circuit
e. None of the above

____ 9. Which describes the LC filter?

a. Large, heavy and expensive
b. Small, light and inexpensive
c. The only filter commonly used
d. Used in low-power circuits
e. Small, light and expensive

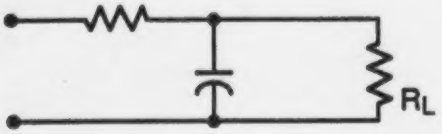
____ 10. The voltage tripler produces an output how many times the AC rms input?

a. Two
b. Three
c. Four
d. 6.28
e. Seven

Match the type of filter configuration to the illustrations shown below.

a. Capacitor filter (RC)
b. Wheatstone filter
c. Pi section filter
d. Inductive input filter
e. Bridge filter

___ 13.



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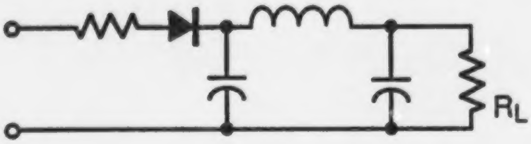

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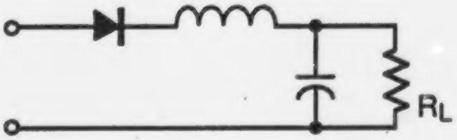

11~

ANSWERS TO UNIT TEST

1.	a	(B19)
2.	b	(B19)
3.	c	(C3)
4.	c	(B18)
5.	d	(B19)
6.	a	(B14)
7.	a	(B19)
8.	a	(B18)
9.	a	(B19)
10.	b	(B19)
11.	a	(B19)
12.	c	(B19)
13.	d	(B19)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VI: SPECIAL DIODES

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to apply knowledge learned about zener, tunnel, varactor and other special diodes to construct and operate a zener regulator. This knowledge will be evidenced by achieving the specified score on the job sheet and unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Match terms concerning special diodes with definitions.

1.2 Identify true statements concerning zener diodes and construct and test a zener regulator circuit.

1.3. Identify true statements concerning the varactor diode and explain its operation.

1.4 Identify true statements concerning the tunnel diode and explain its operation.

1.5 Identify true statements concerning special-purpose diodes.

1.6 Test zener diodes. (competency D13, JS 1.1)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VI: SPECIAL DIODES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

1. Lesson 1: SPECIAL DIODES

    a. Information outline

    b. Transparency masters

    TM 1.1: Reverse characteristic of zener diode
    TM 1.2: Varactor diode

    c. Handouts

    HO 1.1: Zener diode characteristics and schematic symbol
    HO 1.2: Tunnel diode characteristics and schematic symbol

    d. Job sheet

    JS 1.1: Test zener diode

E. Unit test

F. Answers to unit test

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1. Grob, Bernard. Basic Electronics. 5th ed. New York: McGraw-Hill, 1984.

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MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VI: SPECIAL DIODES

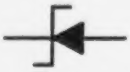
LESSON 1: SPECIAL DIODES

I. Terms, definitions and abbreviations

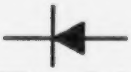
- A. Zener effect--results when reverse bias produces an electric field strong enough to cause a reverse current
- B. Breakdown point--point at which reverse-bias voltage (V_R) overcomes zener voltage (V_Z), allowing current flow
- C. Zener diode--designed to operate in the breakdown region
- D. Zener resistance--resistance of the zener diode in the breakdown region
- E. I_Z--zener current
- F. I_{ZMAX}--maximum current a zener can conduct
- G. I_{ZMIN}--minimum operating current of a zener
- H. P_{ZMAX}--maximum power a zener can dissipate
- I. R_S--series resistor to limit zener current
- J. V_Z--zener voltage

II. Zener diode **(TM 1.1, HO 1.1)**

- A. Comparison with a silicon diode



Zener



Silicon diode

  1. Similar in appearance
  2. The zener diode is a two-lead axial device with the leads labeled as the anode (+) and the cathode (-).
  3. The diode is forward-biased when its anode is more positive than its cathode. It conducts a large forward current (I_F) with a forward voltage drop (V_F) of 0.7 volts.
  4. The diode is reverse-biased when the cathode is more negative than the anode.
     - a. Zeners are generally used in the reverse-biased mode, even though they will operate in the forward-biased mode.
     - b. Unlike the silicon diode, zener diodes conduct in the reverse-biased mode.
     - c. Very little current flows until the reverse-bias voltage (V_R) is greater than the zener voltage (V_Z). This is called the breakdown point.
     - d. At the breakdown point, a large reverse current (I_Z) flows through the diode, while the zener voltage (V_Z) remains fairly constant.

5. Zeners are also called voltage-reference diodes because zener voltage (V_Z) is fairly constant when the diode is conducting.

6. Zener diodes are manufactured with a voltage range of a tenth of a volt to more than 1000 volts. They can handle up to 100 watts of power.

B. Zener operation

1. The most current that a zener diode can conduct is called zener current maximum (I_{ZMAX}).

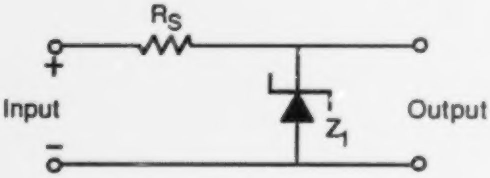
   a. Maximum current (I_{ZMAX}) can be calculated using the manufacturer's specifications for maximum power (P_{ZMAX}) and zener voltage (V_Z).

   $$I_{ZMAX} = P_{ZMAX} / V_Z$$

   b. A good rule of thumb is to operate the zener diode at one half of I_{ZMAX}.

   c. Calculations are done when no resistive load is connected to the circuit.

2. For safe operation, a resistor (R_S) in series with the input voltage limits current through the diode.



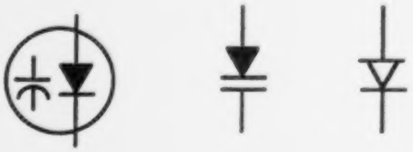
   a. Input voltage should be one volt greater than V_Z to operate the zener diode in the breakdown region.

   b. To find the value of R_S, divide the voltage drop (V_{RS}) of the resistor (R_S) by I_Z.

   $V_{RS} = +V - V_Z$ (+V is the input voltage.)

   $R_S = V_{RS} / I_Z$

III. Varactor diode (also known as a tuning diode, voltage-variable capacitance and epicap) (TM 1.2)



A. Varactors are used in FM radios, television receivers and communication equipment.

B. The varactor diode is operated in reverse bias.

1. Reverse bias causes an increase in the depletion region and acts like a dielectric in a capacitor.

2. As reverse-bias voltage increases, the depletion region (dielectric) decreases and reduces the amount of capacitance.

C. Capacitance values of the diode increase with forward bias. (This operation is not used because the varactor diode loses its capacitive characteristics and functions as a regular diode.)

D. Varactor diodes have a high Q or quality factor.

1. Q refers to the capacitor's efficiency (ratio of energy stored to energy dissipated).

2. The capacitance range is from 1 picofarad to 2K picofarad.

E. Applications

1. Varactors are used to vary frequency of a resonant circuit.

2. Frequency is controlled by reverse-bias voltage, which prevents the DC bias from interfering with L.

3. DC voltage, R and C_2 are used to reverse-bias the diode.

4. Varactors are also used in high-frequency amplifiers, automatic frequency control (AFC), FM radios, and AM transmitters and receivers.

IV. Tunnel diode **(HO 1.2)**

A. Has a heavily doped P-N junction, high barrier voltage, very narrow depletion region and low reverse breakdown voltage

B. As the forward bias increases, electrons are forced through the narrow depletion region at a very high velocity because of the concentration of charges on each side of the junction.

1. Electrons appear to tunnel through the region.

2. Forward bias increases to peak voltage (V_P).

3. As bias is increased, forward current starts to decrease until bias voltage reaches the valley voltage (V_V).

4. Forward current is called valley current (I_V).

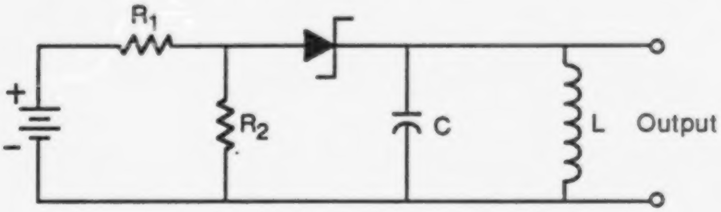
5. The region between V_P and V_V is the negative resistance region.

6. As forward bias voltage increases, forward current increases.

7. Maximum forward current occurs at V_P and V_{FP} (forward voltage peak).

8. V_{FP} is avoided because diode damage occurs if bias voltage exceeds V_{FP}.

C. Applications



1. Oscillator circuits

a. R_1 and R_2 set the diode bias to operate in the negative resistance region.

b. C and L set up the AC output.

c. The tunnel diode causes oscillations to occur in the LC circuit, which in turn change the diode operating point.

d. This action reinforces the current flow through L and C.

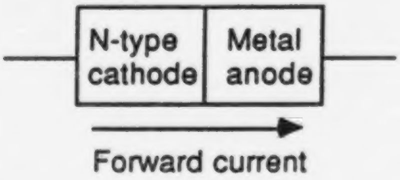
2. Electronic switch

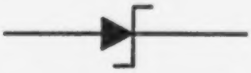
3. High frequency (microwave range)

V. Special-purpose diodes

A. Hot-carrier diode

1. Hot-carrier diodes (HCD) are formed by placing an N-type material in contact with a metal such as gold, silver or aluminum to form a metal-to-semiconductor junction.





Schematic symbol

2. Barrier voltage (often referred to as the Schottky-barrier) in a hot-carrier diode is approximately one-half as great as the barrier voltage within a silicon diode.

3. The HCD operates with electrons as majority carriers; almost no minority carriers are involved.

4. The HCD is able to turn on and off at a very rapid rate.

B. Gunn-effect diode

1. The gunn-effect diode is not a true diode--it does not have a P-N junction but is able to produce a negative resistance characteristic within bulk semiconductor materials.

2. The gunn-effect diode is capable of generating rf signals when used with a resonant circuit.

3. Although not a P-N junction, the gunn-effect diode is usually designed for biasing in one specific direction.

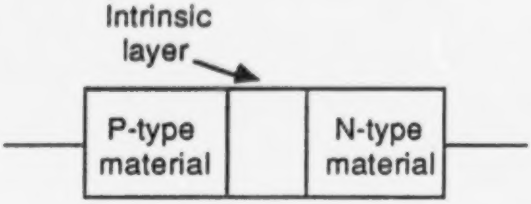
C. PIN diode

1. A PIN diode is a three-layer diode capable of changing from one operating state to another at an extremely rapid rate; it is therefore used in high-frequency applications.

2. Its operation characteristics make it useful as a current-controlled variable resistor.

3. Its internal resistance changes linearly with forward voltage.

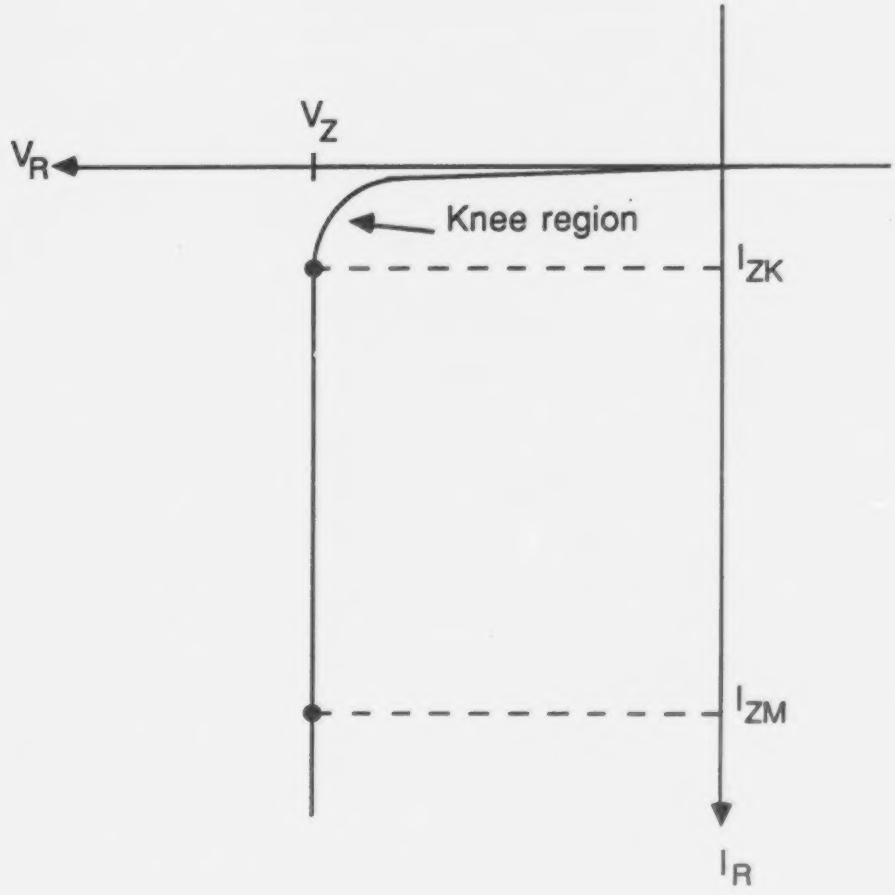
4. Low-bias voltages and currents can control a PIN diode's operation.



D. IMPATT diode

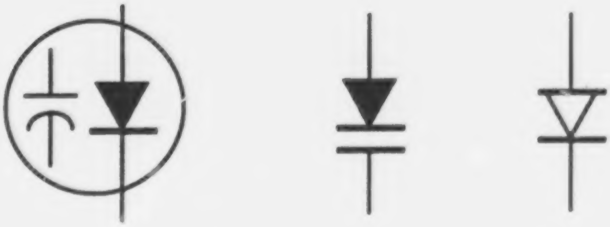
1. The IMPATT (impact avalanche transit time) diode operates within its reverse breakdown region.
2. Its characteristics permit it to be used to generate radio frequency (rf) power.
3. IMPATT diodes are used in high-frequency microwave applications.

REVERSE CHARACTERISTIC OF ZENER DIODE

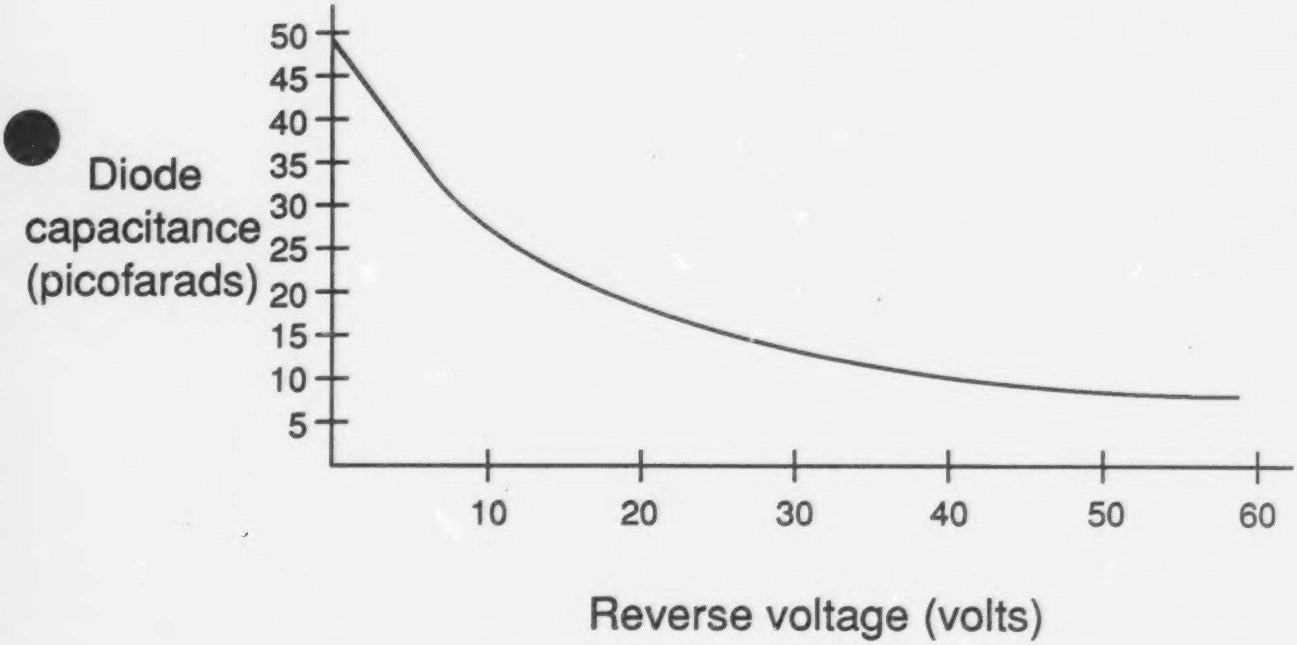


TM 1.2

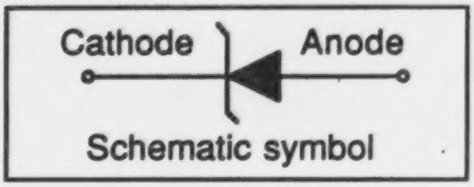
VARACTOR DIODE

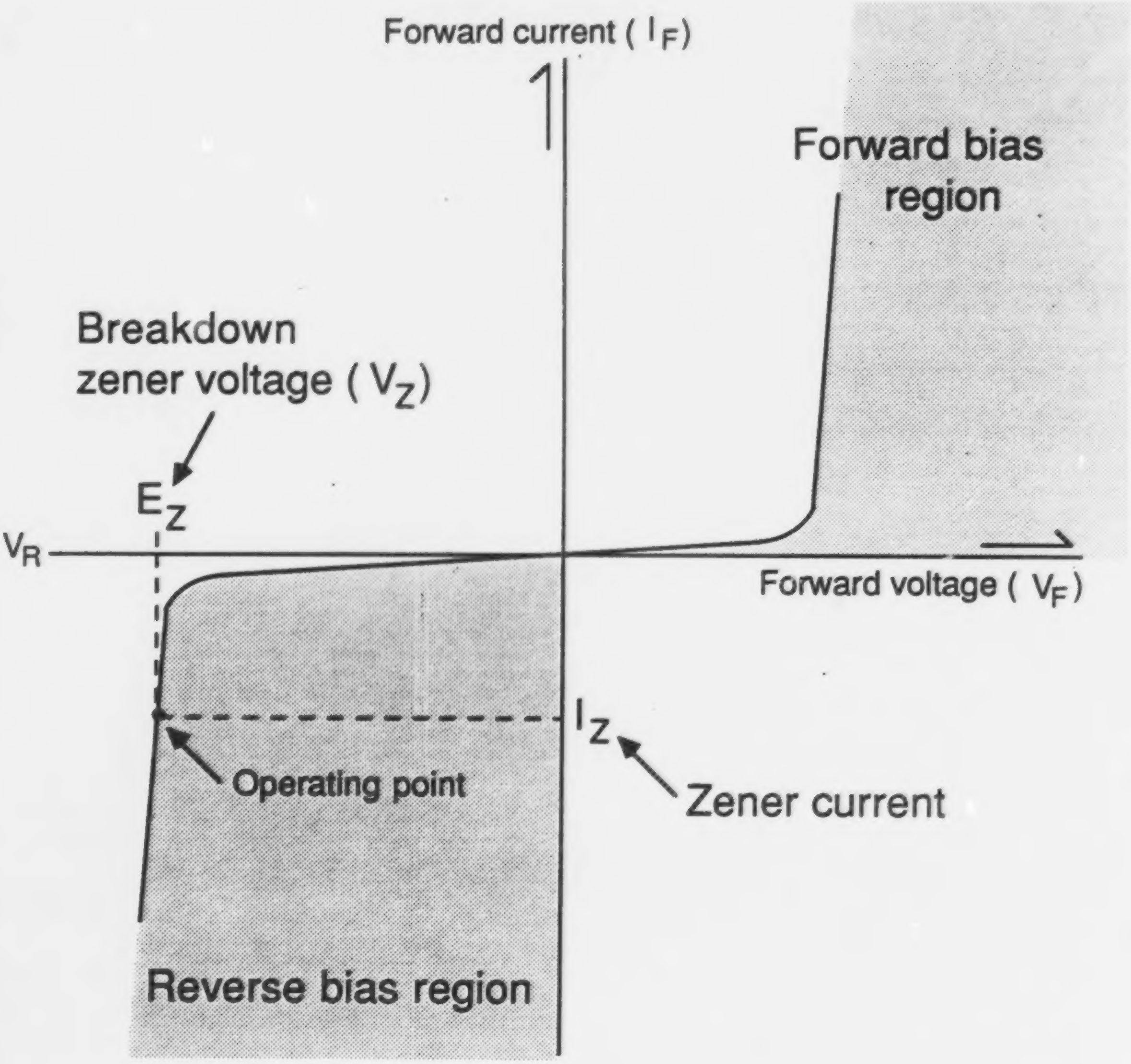


Schematic symbols

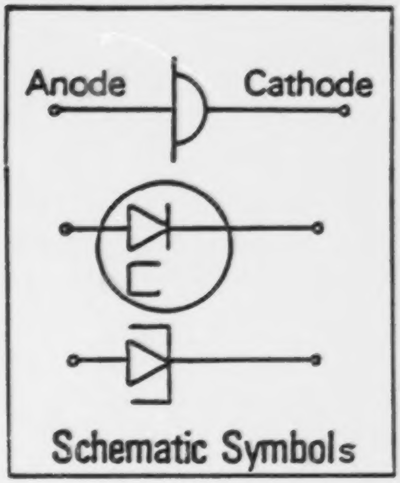


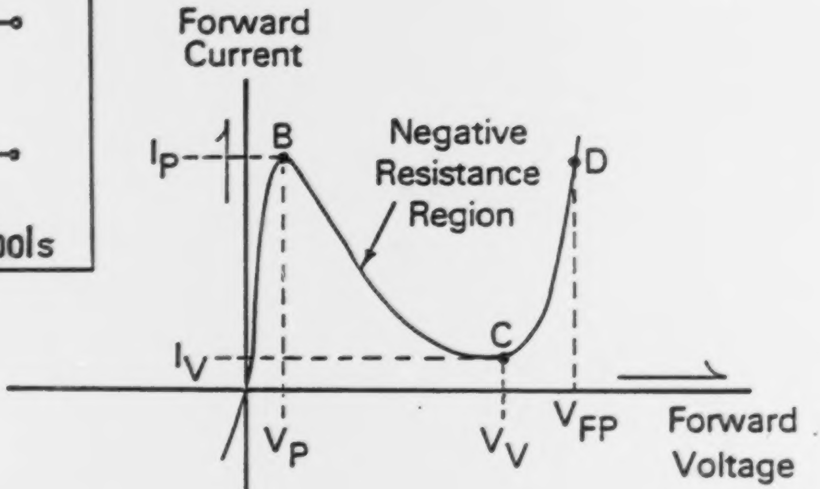
ZENER DIODE CHARACTERISTICS AND SCHEMATIC SYMBOL


Cathode
Anode
Schematic symbol



TUNNEL DIODE CHARACTERISTICS AND SCHEMATIC SYMBOL


Anode
Cathode
Schematic Symbols



B – I_P - Peak-Point Current
V_P - Peak-Point Voltage
C – I_V - Valley- Point Current
V_V - Valley-Point Voltage
D V_{FP} - Forward-Point Voltage

Note:
Negative Resistance
Region Exists Between
Points B and C

TEST ZENER DIODE

Equipment:

DC power supply (0-10 volts)	Breadboard
5.1 volt zener diode, 1 watt	Hook-up wire
62Ω, 1 watt resistor	VOM

Procedure:

Evaluation
3 2 1 N

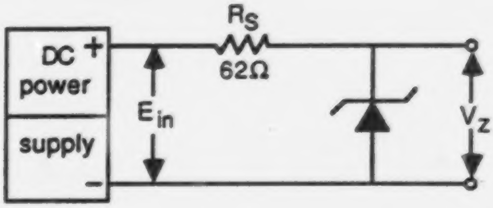
1. Measure resistance from the zener's anode to the cathode. Reverse ohmmeter leads and read the zener's resistance in the reverse direction. — — — —

   Anode-cathode R = ______ ; cathode-anode R = _______

   NOTE: Front-to-back resistance should be a large ratio if the zener diode is a good one.

2. Connect the circuit illustrated. — — — —

   — — — —



3. Set the power supply to 0V output. Turn on the power supply. Set values as listed in the table and record the value of V_Z for each V_{in} listed in the chart below.

V_{in}	0	1	2	3	4	5	6	7	8	9
V_Z										

3. At what voltage did regulation begin to occur? _____ — — — —

4. Return equipment to its proper storage area. — — — —

Average of above evaluations* — — — —

*This average is the student's final evaluation for competency D13: Test diodes.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VI: SPECIAL DIODES

UNIT TEST

Select the option which best answers the question or completes the statement.

____ 1. How many leads does a zener diode have?

a. One
b. Two
c. Three
d. Four
e. Five

____ 2. Operating as a voltage regulator, how is a zener diode biased?

a. Forward
b. Not conducting
c. Improperly used
d. Reverse
e. Not biased

____ 3. Which diode does not have a P-N junction?

a. PIN
b. Schottky barrier
c. IMPATT
d. Gunn-effect
e. None of the above

____ 4. What is the limit of current a zener diode can conduct?

a. V_Z
b. P_{ZMAX}
c. I_{ZMAX}
d. I_{ZMIN}
e. None of the above

____ 5. Which is used in the construction of hot carrier diodes?

a. Gold or silver
b. Platinum or silver
c. Gold or platinum
d. Aluminum or copper
e. Silver or copper

____ 6. Which does a tunnel diode have?

a. Positive resistance region
b. Lightly doped P-N junction
c. Negative resistance region
d. Low barrier voltage
e. None of the above

___ 7. Which is also called a tuning dish?

- a. Zener
- b. Varactor
- c. IMPATT
- d. Tunnel
- e. None of the above

___ 8. What is a zener also called?

- a. Voltage reference diode
- b. Tuning diode
- c. Hot carrier diode (HCD)
- d. PIN diode
- e. Varactor diode

___ 9. Which diode is a three-layer device?

- a. IMPATT
- b. PIN
- c. Schottky barrier
- d. Gunn-effect
- e. None of the above

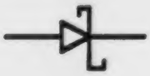
___ 10. Where can the tunnel, gunn-effect and IMPATT diodes be used?

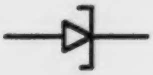
- a. High-frequency applications
- b. Microwave ovens
- c. Low-frequency applications
- d. FM radio
- e. None of the above

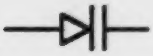
___ 11. Which abbreviation denotes the greatest zener force dissipation?

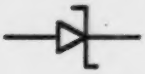
- a. I_Z
- b. I_{ZMAX}
- c. P_{ZMAX}
- d. R_S
- e. V_Z

Match the diode name to the schematic symbol.

___ 12. 

___ 13. 

___ 14. 

___ 15. 

a. Hot carrier

b. IMPATT

c. Tunnel

d. Varactor

e. Zener

ANSWERS TO UNIT TEST (D13)

1. b
2. d
3. d
4. c
5. a
6. c
7. b
8. a
9. b
10. a
11. c
12. a
13. c
14. d
15. e

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VII: ZENER-REGULATED POWER SUPPLY

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to discuss the regulation, operation and the circuits involved with a zener-regulated power supply. This knowledge will be evidenced by achieving a specified score on the unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Match terms and definitions concerning regulation.

1.2 Calculate the percent of regulation in a regulated power supply.

1.3 Identify zener regulator configuration.

1.4 Discuss the use of a zener diode with a transistor to regulate a power supply in a transistor-shunt regulator.

1.5 Discuss the use of a zener diode with a transistor to regulate a power supply in a series regulator.

1.6 Identify other regulator circuits. (competency C6)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VII: ZENER-REGULATED POWER SUPPLY

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

  1. Lesson 1: REGULATED POWER SUPPLIES

    a. Information outline

    b. Transparency masters

      TM 1.1: Voltage regulation
      TM 1.2: Zener regulators
      TM 1.3: Series regulators
      TM 1.4: Load protection

E. Unit test

F. Answers to unit test

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A. Books

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MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VII: ZENER-REGULATED POWER SUPPLY

LESSON 1: REGULATED POWER SUPPLIES

I. Terms and definitions

   A. Regulation--holding the DC output voltage approximately constant

   B. Shunt--bypasses, redirects or blocks current flow (in parallel with current flow)

II. Voltage regulation **(TM 1.1)**

   A. A regulator circuit is added to a power supply to maintain a constant output voltage.

   B. As the load or input voltage changes, a regulator compensates for changes and keeps output voltage at a specific value.

   C. The load regulation factor is used to determine a power supply's ability to maintain a constant DC output voltage.

      1. Load regulation factor

         E_{NL} = output voltage with no load
         E_{FL} = output voltage with full load

         % of regulation = $(E_{NL} - E_{FL}) / E_{FL} \times 100$

      2. Regulation improves as the percentage of regulation decreases.

      3. Many power supplies have 0.1% regulation.

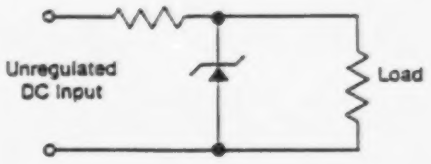
III. Zener regulator **(TM 1.2)**

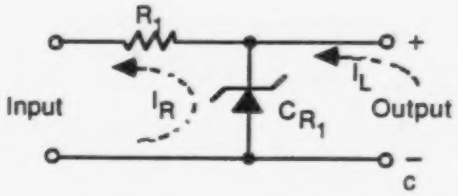
   A. A zener diode is used in a simple regulator.

   B. The zener is selected to operate in its breakdown region and to match voltage requirements of the power supply.

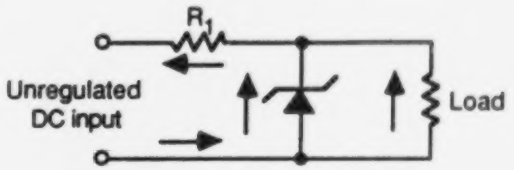
   C. A series resistor (R_1) is selected to limit zener current to a safe level with no load connected.

   D. With no load connected, most of the current flows through the zener.





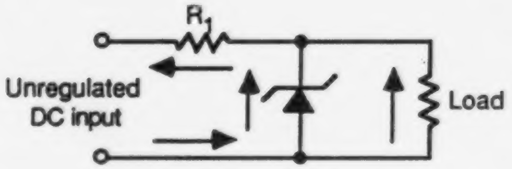
E. A load is applied to the circuit in parallel with the zener diode.



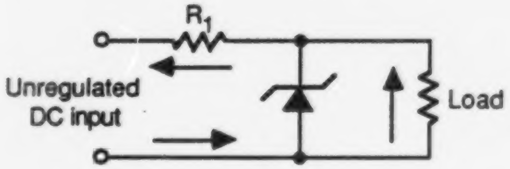
F. The current of R_1 is the sum of the zener and load currents.

G. Zener diode current changes with load current changes to maintain a constant output voltage.

H. As the load requirement increases, current flow through the zener diode decreases.



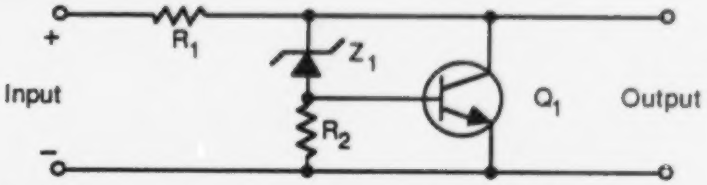
I. If the load requires too much current, the zener current will fall below the breakdown region and regulation will stop.



J. This circuit is called a zener-diode shunt regulator.

IV. Transistor shunt regulator

A. A transistor and zener diode can be used in this regulator.

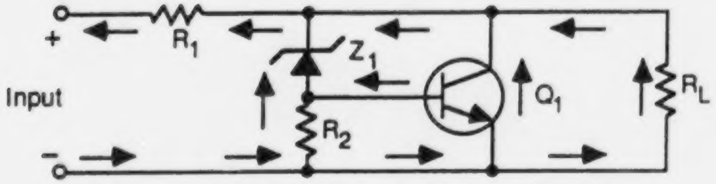


B. Zener voltage plus base-to-emitter voltage equals output voltage.

C. If load current decreases, Z_1 causes the base current of Q_1 to increase, which causes Q_1 to increase the collector current.

D. This current increase causes a larger voltage drop across R_1, maintaining the output voltage.

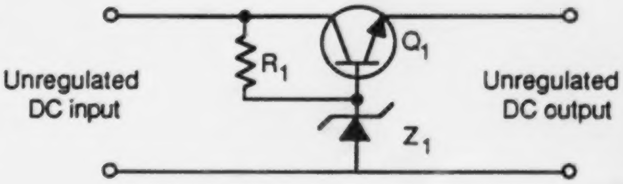
E. If load current increases, Z_1 will conduct less, causing Q_1 to draw less current and R_1 to have a smaller voltage drop, allowing more voltage for the load.



V. Series regulator (TM 1.3)

A. A zener diode is used to bias the base of the transistor to control regulation.

B. The transistor is in series with the load and thus provides series regulation.



C. As load voltage increases, emitter-base voltage decreases, causing Q_1 to conduct less, which increases the internal resistance of Q_1.

D. The increase in the resistance of Q_1 causes an increased voltage drop across the transistor, which decreases voltage to the load.

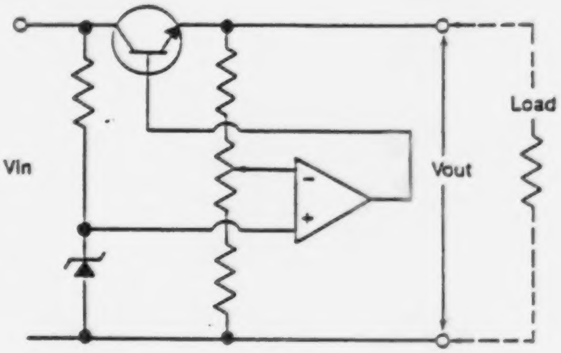
E. A decrease in the load voltage has the opposite effect.

F. A VDR (voltage-dependent resistor) is used in voltage spike protectors. A VDR is also called an MOV (metal oxide varistor).

1. VDR components are placed in power supply circuits to protect other circuits from catastrophic power supply failure.
2. Component breakdown or voltage spikes (lightning strikes) can cause abnormally high voltages. A VDR is designed to have very high resistance until abnormally high voltages appear across it.
3. When abnormally high voltages occur, the resistance of the VDR decreases dramatically, causing the circuit fuse or circuit breaker to open. This action attempts to protect the voltage-sensitive circuits from damage.

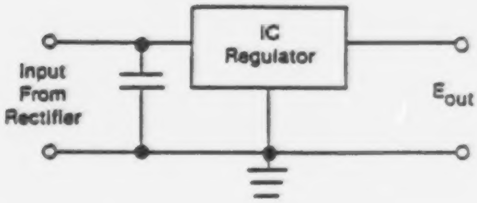
VI. Other regulators (TM 1.4)

A. An op-amp can be used as the error detector and amplifier in a feedback regulator circuit.



135

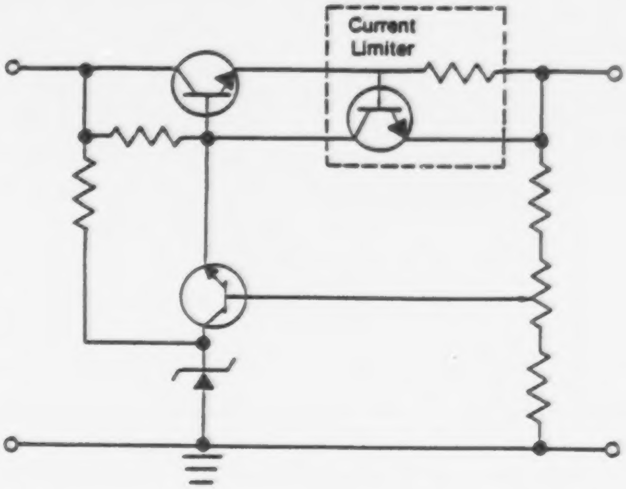
B. Complete regulators are constructed as three-terminal I.C. packages including protective circuits, which make them resistant to burn-out.


IC
Regulator
Input
From
Rectifier
E_{out}

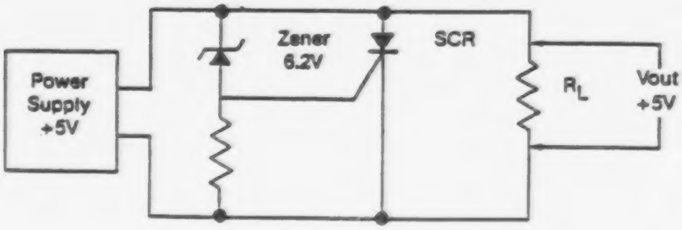
C. Overload protection circuits

1. The fuse and circuit breaker are the simplest forms of overload protection.

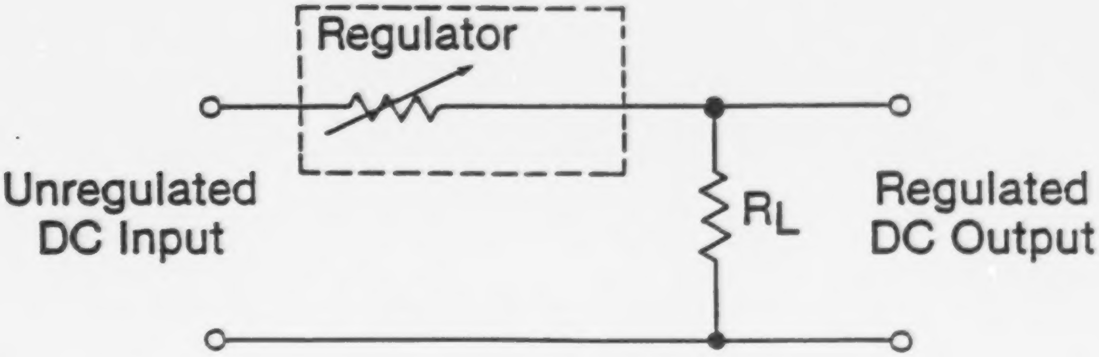
2. A current-limiting circuit can be added to a regulator to protect the series-regulator transistor from short circuits in the load.


Current
Limiter

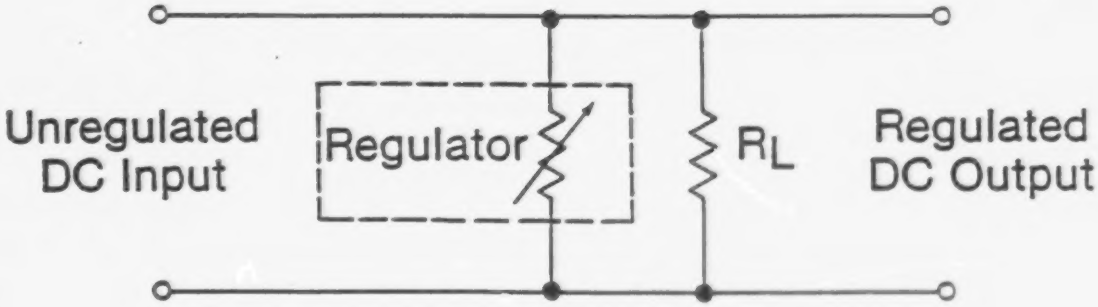
3. The "crowbar" circuit is used to protect the load from an over-voltage condition.


Power
Supply
+5V
Zener
6.2V
SCR
R_L
Vout
+5V

VOLTAGE REGULATION


Regulator
Unregulated
DC Input
R_L
Regulated
DC Output

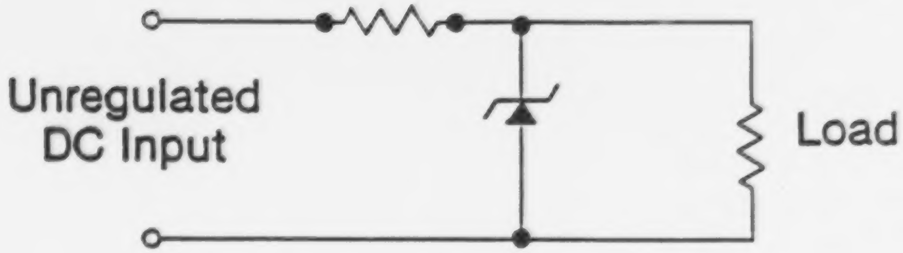
Series Regulation


Unregulated
DC Input
Regulator
R_L
Regulated
DC Output

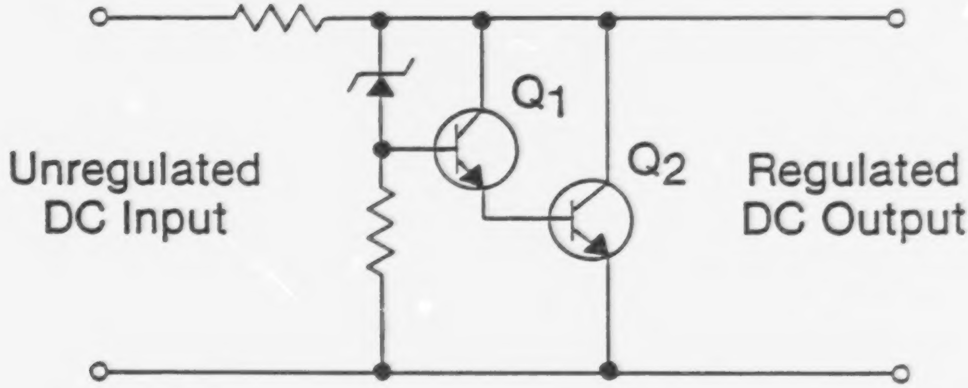
Shunt Regulator

$$\% \text{ Regulation} = \frac{E_{NL} + E_{FL}}{E_{FL}} \times 100$$

ZENER REGULATORS

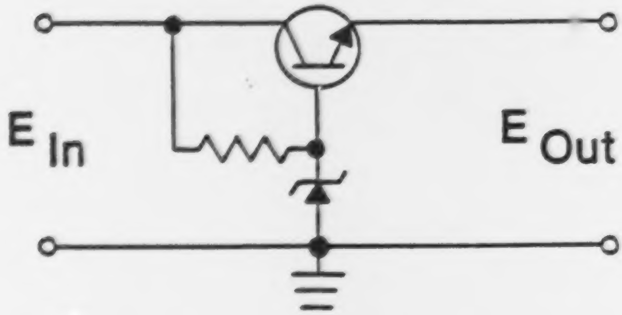

Unregulated
DC Input
Load

Zener-Type Shunt Regulator

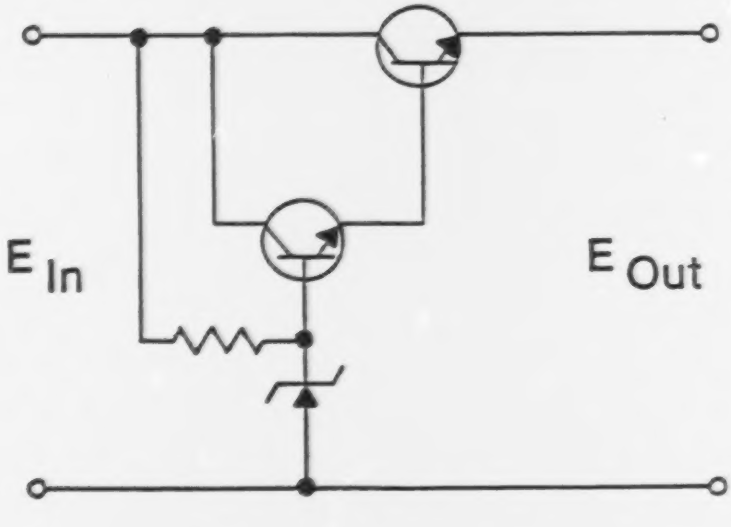

Q1
Q2
Unregulated
DC Input
Regulated
DC Output

Improved Zener Diode Shunt-Type Regulator

SERIES REGULATORS

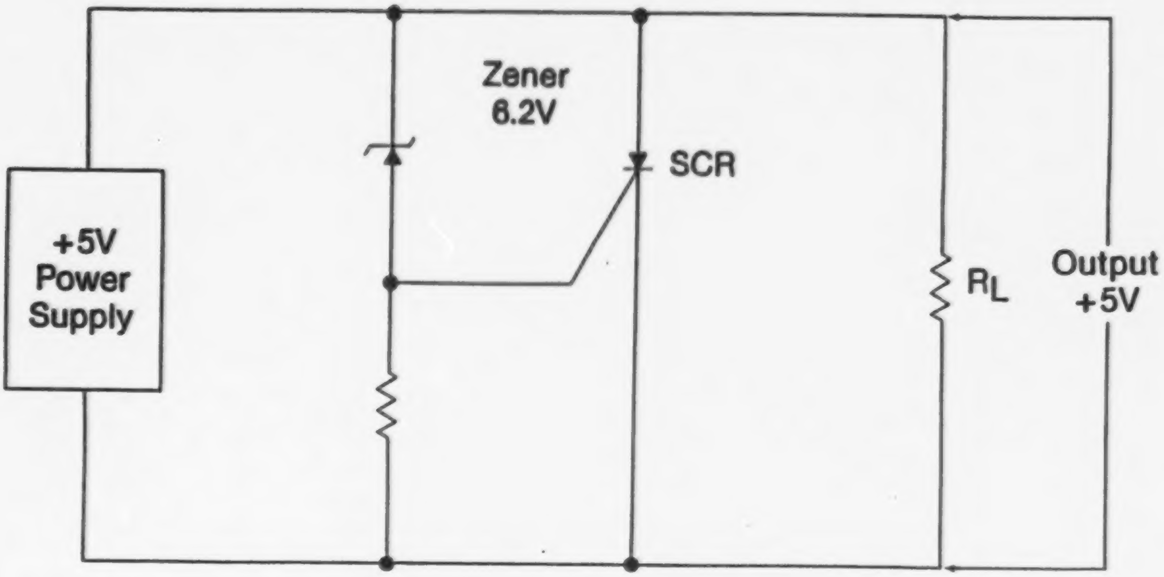


Emitter Follower Regulator



Darlington Configuration

LOAD PROTECTION


Zener
6.2V
SCR
+5V
Power
Supply
R_L
Output
+5V

“Crowbar” Protection Circuit

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VII: ZENER-REGULATED POWER SUPPLY

UNIT TEST

Match the terms on the right with definitions on the left.

____ 1. Used to step AC up or down

____ 2. Used for reference voltage or regulation (zener)

____ 3. Used as comparator of output and reference

____ 4. Used to filter pulsating DC

____ 5. Used to rectify AC voltage levels by switching on and off

____ 6. Used as active control element to regulate voltage or current

____ 7. Required with center-tapped output for some types of rectifier circuits

____ 8. Component or elements of a power supply that reduce ripple

____ 9. Can have multiple taps for varying output voltage

____ 10. Used for rectification of AC (solid-state device)

____ 11. Directs or blocks current flow

a. Rectifier

b. Capacitor

c. Shunt

d. Transformer

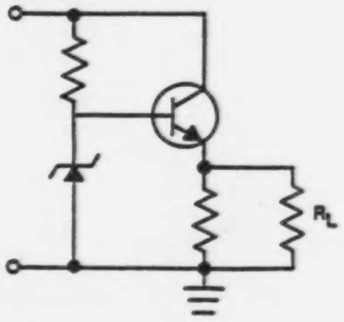
e. Transistor

ab. Inductor

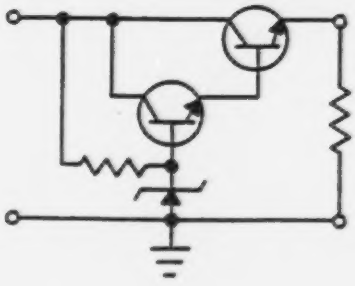
ac. Filter

ad. Zener diode

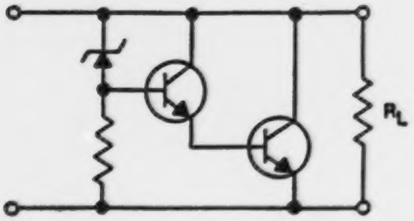
Mark "a" if the regulator configuration is a series type and "b" if it is a shunt type.

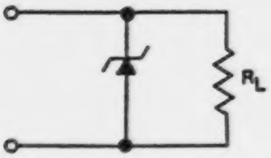


____ 12.



____ 13.





____ 14.

____ 15.

Select the option which answers the question or completes the statement.

____ 16. If $E_{no\ load}$ = 15V and E_{load} = 12V, what is the percent of regulation?

a. .25
b. 25
c. 100
d. 150
e. 250

____ 17. If $E_{no\ load}$ = 11V and E_{load} = 8V, what is the percent of regulation?

a. .375
b. 3.75
c. 37.5
d. 375
e. 3750

____ 18. Which device is used in voltage spike protectors?

a. Circuit breaker
b. Op amp
c. Transistor shunt regulator
d. Voltage-dependent resistor
e. Zener diode

____ 19. Which device is also known as an MOV?

a. Circuit breaker
b. Op amp
c. Transistor shunt regulator
d. Voltage-dependent resistor
e. Zener diode

ANSWERS TO UNIT TEST

1.	d	(C1)
2.	ad	
3.	e	(D3)
4.	ac	(B19)
5.	a	(D2)
6.	e	(D3)
7.	d	(C1)
8.	b	(B19)
9.	d	(C1)
10.	a	(D2)
11.	c	(C6)
12.	a	(C5)
13.	a	(C5)
14.	b	(C6)
15.	b	(C6)
16.	b	(C6)
17.	c	(C6)
18.	d	(D12)
19.	d	(D12)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VIII: BIPOLAR JUNCTION TRANSISTOR (BJT)

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to discuss the operation, biasing and amplification of the bipolar junction transistor. This knowledge will be evidenced by achieving a specified score on the job sheets and unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Match terms and definitions concerning bipolar junction transistors.

1.2 Describe general characteristics of a transistor.

1.3 Identify the direction of current flow in NPN and PNP transistors.

1.4 Identify the characteristics of transistor emitters, bases and collectors. (competency D3)

1.5 Test transistors. (competency D14, JS 1.1)

2.1 Identify common-base transistor circuit characteristics.

2.2 Identify characteristics of a common-collector transistor circuit.

2.3 Identify characteristics of a common-emitter transistor circuit.

2.4 Match classes of operation with descriptions.

2.5 Describe transistor biasing techniques. (competency D3)

2.6 Construct and test a common-emitter circuit. (partial D4 and D14, JS 2.1)

2.7 Construct and test a common-base circuit. (partial D4 and D14, JS 2.2)

2.8 Construct and test a common-collector circuit. (competency D4 and D14, JS 2.3)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VIII: BIPOLAR JUNCTION TRANSISTOR (BJT)

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: BJT OPERATION

   a. Information outline

   b. Transparency masters

      TM 1.1: Electron flow in NPN and PNP transistor circuits
      TM 1.2: PNP transistor majority current carriers

   c. Handouts

      HO 1.1: Typical transistor types
      HO 1.2: Various transistor cases
      HO 1.3: Transistor block diagrams and schematics
      HO 1.4: Correctly biased transistors

   d. Job sheet

      JS 1.1: Test transistors

2. Lesson 2: TRANSISTOR AMPLIFIER CIRCUITS

   a. Information outline

   b. Transparency masters

      TM 2.1: Common-base amplifier (PNP) circuit
      TM 2.2: Common-collector amplifier (NPN) circuit
      TM 2.3: Common-emitter amplifier (NPN) circuit

   c. Handout

      HO 2.1: Comparison of transistor circuit combinations

   d. Job sheets

      JS 2.1: Construct and test a common-emitter circuit
      JS 2.2: Construct and test a common-base circuit
      JS 2.3: Construct and test a common-collector circuit

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Grob, Bernard. Basic Electronics. 5th ed. New York: McGraw-Hill, 1984.

2. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.

3. Hughes, Fredrick W. Basic Electronics: Theory and Experimentation. Englewood Cliffs, N.J.: Prentice-Hall, 1984.

4. Malvino, Albert Paul. Semiconductor Circuit Approximations. 4th ed. New York: McGraw-Hill Book Co., 1985.

5. Schuler, Charles A. Electronics: Principles and Applications. New York: McGraw-Hill, 1979.

6. Weir, Gregory. Fundamentals of Mathematics: Outline and Review Problems for Electronic Circuit Fundamentals. Englewood Cliffs, N.J.: Prentice-Hall, 1987.

B. Curriculum guides

1. Hartman, Lonnie. Basic Electronics. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

2. Vorderstrasse, Ron. General Electronics Technician. Stillwater, Okla.: Mid-America Vocational Curriculum Consortium, 1987.

NOTES TO THE INSTRUCTOR

A. Suggested supplemental material

1. Bipolar Transistor Amplifiers (E-87-330 video). Sedalia, MO: The Media Center, State Fair Community College, 1987. (Available for purchase from SFCC; available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VIII: BIPOLAR JUNCTION TRANSISTOR (BJT)

LESSON 1: BJT OPERATION

I. Terms and definitions

  A. Analog device--component that operates within a range of voltage levels

  B. Base--region which lies between the emitter and collector of a transistor into which minority carriers are injected

  C. Bias--external electrical potential (voltage) applied to a P-N junction

  D. Collector--section of a transistor in which majority current carriers are collected out of the device

  E. Cutoff--condition when all normal charge carriers stop flowing in a device

  F. Discrete device--component composed of one functional element as compared to an integrated-circuit device composed of many elements
  Examples: Transistor, diode, silicon-controlled rectifier, resistor

  G. Emitter--most heavily doped section of transistor where majority current carriers travel inward and thus are emitted into the device

  H. Input impedance--total opposition to current at a device's input

  I. Linear device--component that has the same gain or reaction to the input over the operating range regardless of frequency or environmental factors such as temperature and humidity

  J. Output impedance--total opposition to current at a device's output

  K. Saturation--point at which an increase in collector voltage no longer causes an increase in collector current and an increase in base current no longer causes an increase in collector current

  L. Transistor--solid-state semiconductor device usually having three terminals; conductivity varies according to voltage and current inputs

II. Bipolar transistor characteristics (HO 1.1)

  A. A bipolar transistor is a three-terminal current-controlled semiconductor device containing two P-N junctions.

    1. The three sections of the bipolar transistor are the emitter (E), base (B) and collector (C).

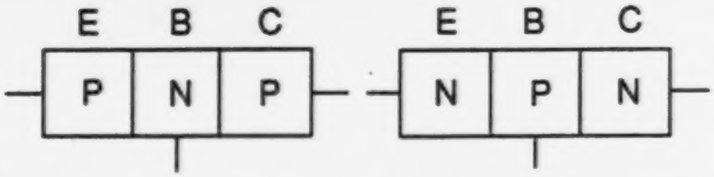
    2. The sections are separated by two P-N junctions.

  B. Transistors are made from silicon and germanium.

  C. Major types of bipolar transistors

    1. The PNP transistor consists of P-type material for the emitter, N-type material for the base and P-type material for the collector.

2. The NPN transistor consists of N-type material for the emitter, P-type material for the base and N-type material for the collector.



D. Bipolar transistors are used primarily to increase the amplitude or strength of electronic signals and for switching.

E. Bipolar transistors are packaged in a specially designed container to improve temperature stability, protect the device and support the transistor and its interconnecting leads.

F. Bipolar transistor operation characteristics

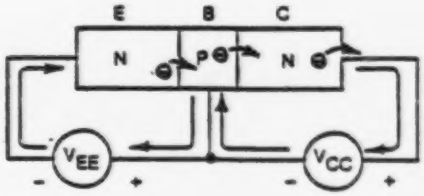
1. The collector-base junction of a bipolar transistor is normally reverse biased.

2. The emitter-base junction of a bipolar transistor is normally forward biased.

III. Current flow in transistors (TM 1.1, 1.2)

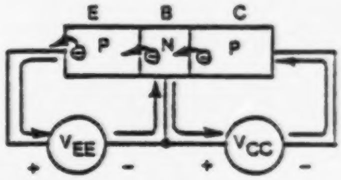
A. In NPN transistors, free electrons flow from emitter to base and from base to collector, causing current flow through the transistor.

NOTE: Since the base is narrow and lightly doped, only about 5% of the electrons flow from the emitter through the base. The remaining electrons flow through the base to the collector.



B. In PNP transistors, free electrons flow from collector to base and from base to emitter causing current flow.

NOTE: Since the emitter-base junction is a low-resistance region, the small input signal applied to the emitter results in maximum current flow.



C. VEE is the battery or power supply to forward bias the emitter-base junction.

D. VCC is the battery or power supply to reverse bias the collector- base junction.

E. The relationship between emitter current (Ie), base current (Ib) and collector current (Ic) is established in the following equations.

1. Ie = Ib + Ic

2. Ic = Ie - Ib

3. Ib = Ie - Ic

F. Leads for common transistor cases (HO 1.2)

NOTE: There are many types of transistor cases identical to those of silicon-controlled rectifiers and field-effect transistors. Because the leads are not standard, it is best to consult a reference manual to determine the leads for the particular part number.

IV. Characteristics of transistor emitters, bases and collectors

A. Emitter

1. Most heavily doped section of transistor
2. Has most majority current carriers
3. Carries all current that passes into or out of transistor
4. Indicated schematically by an arrowhead

B. Base

1. Constructed very narrowly to improve transistor frequency response
2. Controls current flow through transistor
3. Contains material opposite other two sections of transistor
4. Carries only small portion of current passing into or out of transistor
5. Indicated schematically by a perpendicular line

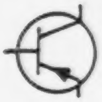
C. Collector

1. Often connected to metal case of transistor
2. Carries large amount of total current into or out of transistor
3. Indicated schematically by a diagonal line

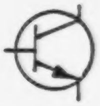
D. Circuit symbols of various transistor types (HO 1.3, 1.4)

NOTE: The emitter lead in both symbols is the one with the arrowhead.

1. PNP transistor

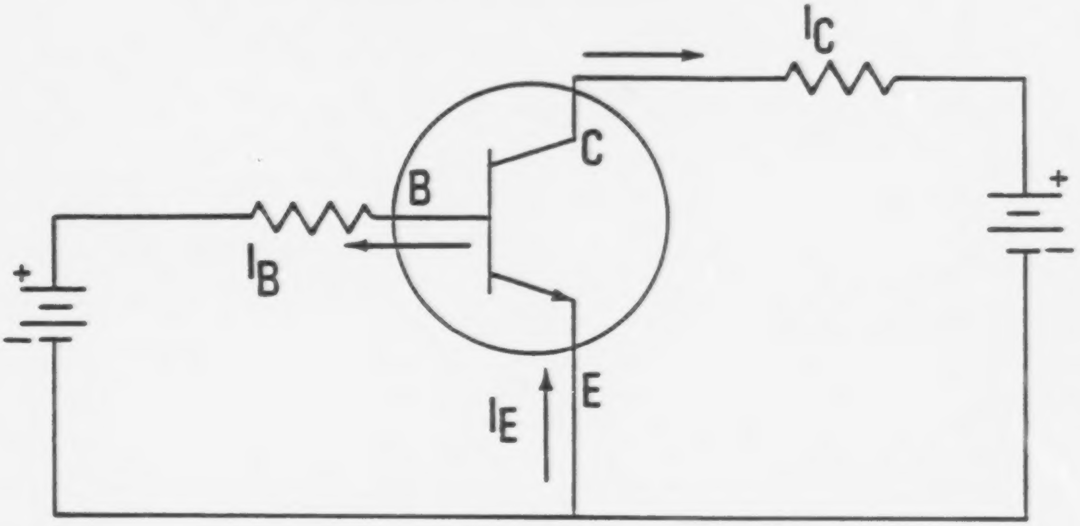


2. NPN transistor



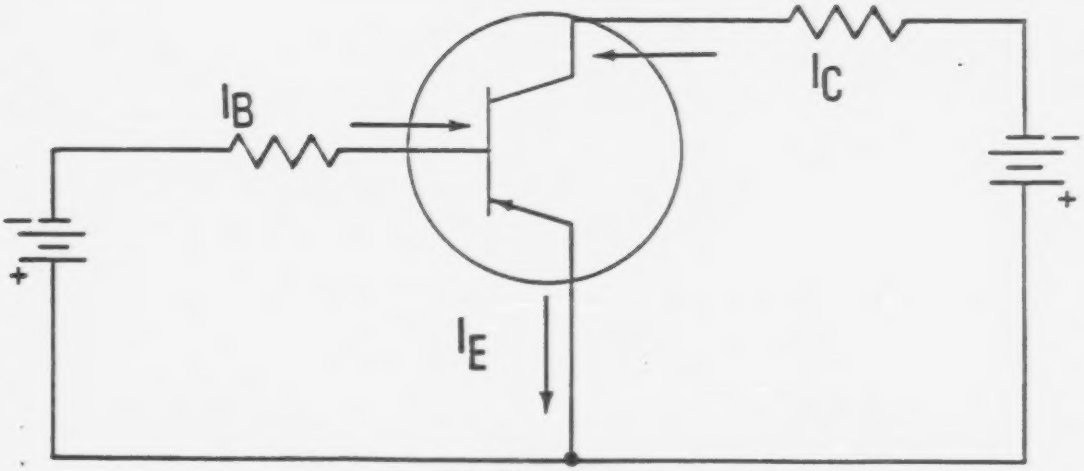
TM 1.1

ELECTRON FLOW IN NPN AND PNP TRANSISTOR CIRCUITS



$I_E=I_B+I_C$

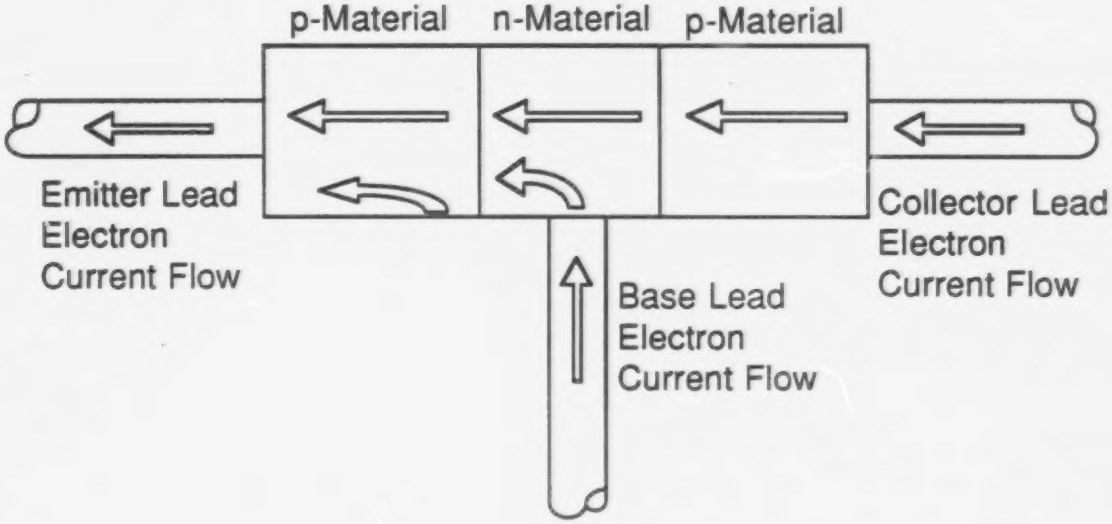
NPN Circuit

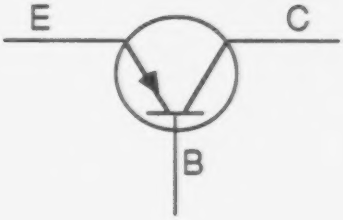


$I_E=I_B+I_C$

PNP Circuit

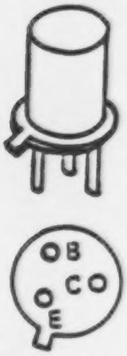
PNP TRANSISTOR MAJORITY CURRENT CARRIERS


p-Material
n-Material
p-Material
Emitter Lead Electron Current Flow
Collector Lead Electron Current Flow
Base Lead Electron Current Flow

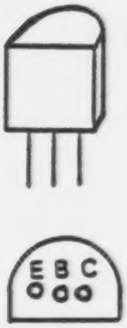


TYPICAL TRANSISTOR TYPES

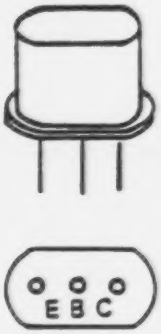
Small Signal Transistors



(Bottom View)

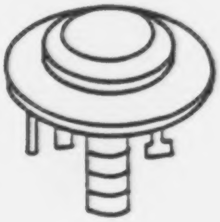


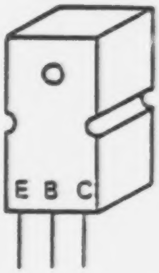
(Bottom View)

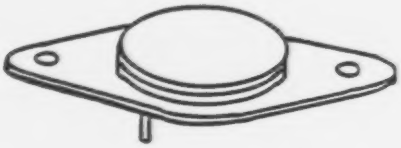


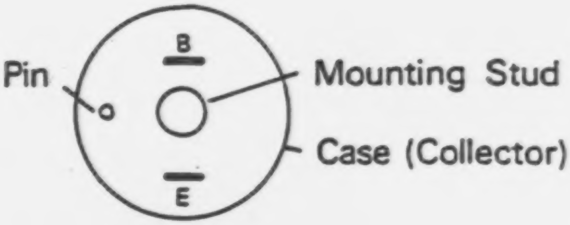
(Bottom View)

Power Transistors

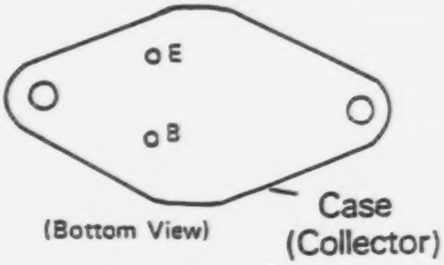







B
Pin
Mounting Stud
Case (Collector)
E

(Bottom View)

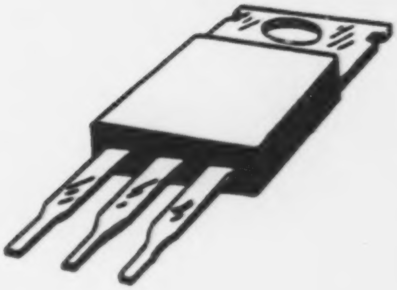

E
B
Case
(Collector)

(Bottom View)

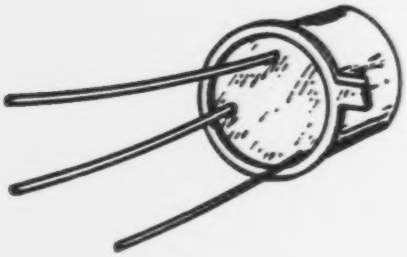
NOTE: There are other base diagrams. See manufacturer's catalog for others.

VARIOUS TRANSISTOR CASES

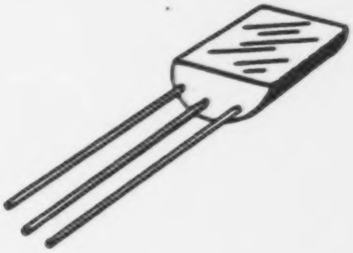
TO-220 Case



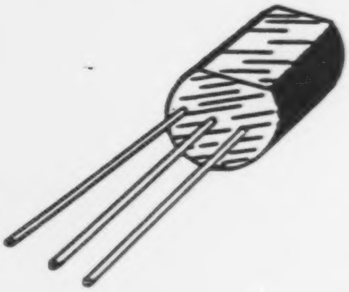
TO-5 Case



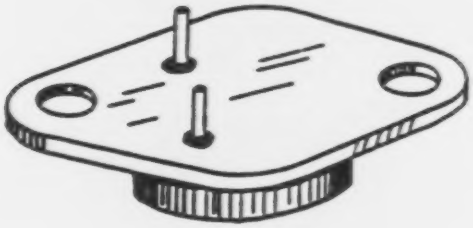
TO-23 Case



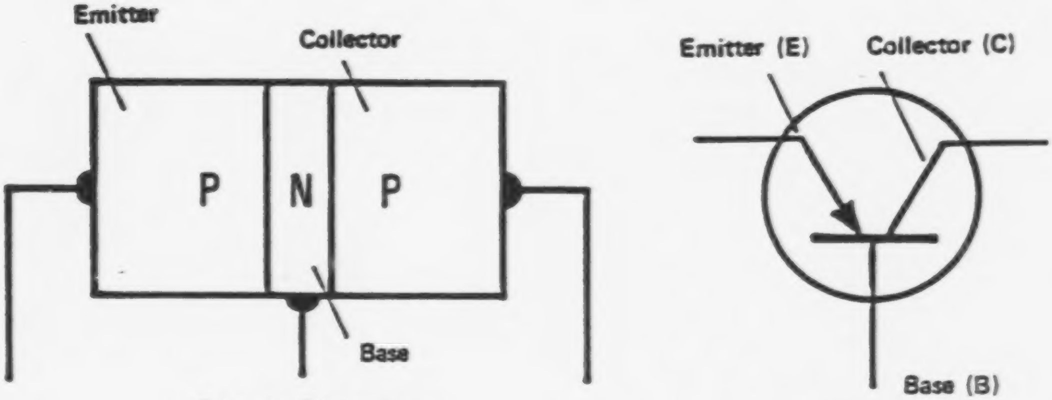
TO-20 Case



TO-3 Case



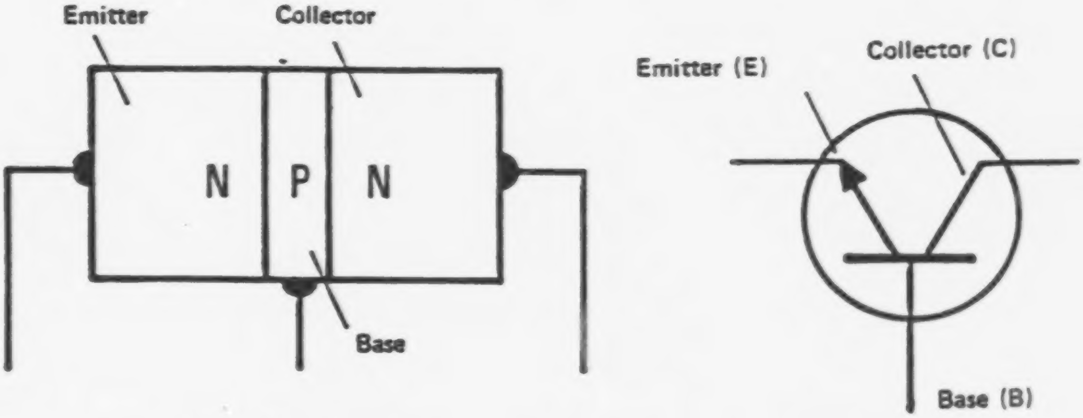
TRANSISTOR BLOCK DIAGRAMS AND SCHEMATICS


Emitter
Collector
P
N
P
Base
Emitter (E)
Collector (C)
Base (B)

Block Diagram

Schematic

PNP Transistor


Emitter
Collector
N
P
N
Base
Emitter (E)
Collector (C)
Base (B)

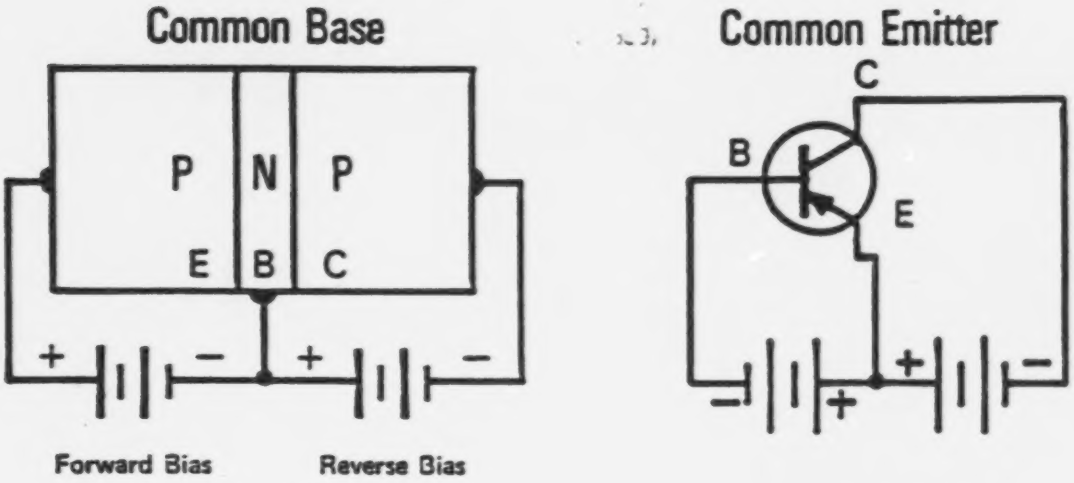
Block Diagram

Schematic

NPN Transistor

NOTE: In both PNP and NPN transistors, the arrow on the emitter lead points toward the N-type material.

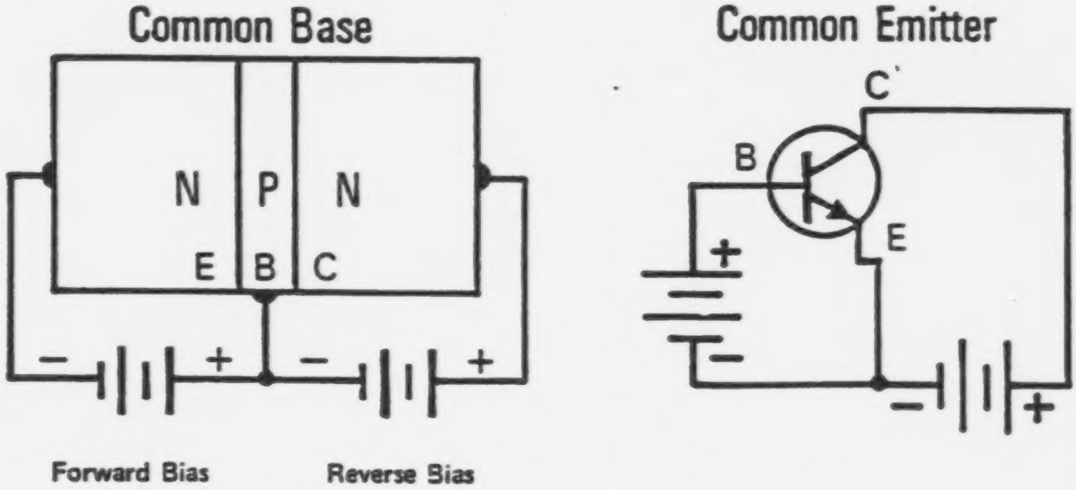
CORRECTLY BIASED TRANSISTORS


Common Base
P
N
P
E
B
C
+
−
+
−
Forward Bias
Reverse Bias
Common Emitter
C
B
E
−
+
+
−

Block

Schematic

PNP Transistor Bias


Common Base
N
P
N
E
B
C
−
+
−
+
Forward Bias
Reverse Bias
Common Emitter
C
B
E
+
−
−
+

Block

Schematic

NPN Transistor Bias

TEST TRANSISTORS

Equipment:

Assortment of transistors (both signal and power types)
Ohmmeter
Transistor tester (if available)

	Procedure:	Evaluation 3	2	1	N
1.	Carefully examine the assortment of transistors and note the differences in size, shape and lead arrangements. Choose two signal transistors and one power transistor.	___	___	___	___
2.	Determine which ohmmeter lead is positive and which lead is negative.	___	___	___	___
	NOTE: Determine this from the manufacturer's instruction book or by measuring the voltage with a voltmeter.				
3.	Identify the emitter, base and collector leads.	___	___	___	___
4.	Place the ohmmeter on R x 100 range.	___	___	___	___
	NOTE: There may be too much voltage if the ohmmeter is placed in a high range.				
5.	Determine the forward-biased emitter base junction. Place the positive ohmmeter lead on the emitter lead and the negative ohmmeter lead on the base lead. Note the resistance reading.	___	___	___	___
6.	Place the negative ohmmeter lead on the emitter and the positive ohmmeter lead on the base. Note the resistance reading. Compare the two resistance readings.	___	___	___	___
7.	Repeat steps 1 through 4 for the collector-base junction.	___	___	___	___
8.	From the above reading, determine transistor quality. If the transistor tested was good, state whether it is PNP or NPN. If the transistor tested was bad, state where it was open or shorted.	___	___	___	___
9.	If your lab has a transistor tester, check the transistor following the instructions given in the operations manual.	___	___	___	___

Emitter-base junction	Collector-base junction
R_{EB} = ______	R_{CB} = ______
R_{BE} = ______	R_{BC} = ______

Type of transistor:

		3	2	1	N
10.	Return equipment to its proper storage area.	___	___	___	___
	Average of above evaluations*	___	___	___	___

*This average is the student's partial evaluation for competency D14: Test transistors.

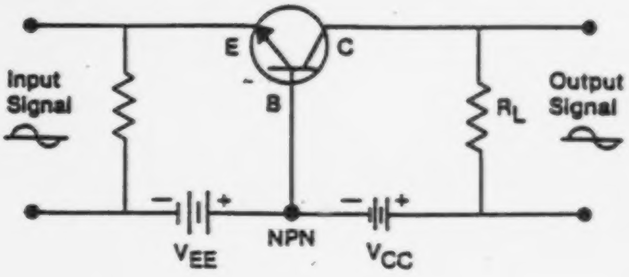
MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VIII: BIPOLAR JUNCTION TRANSISTOR (BJT)

LESSON 2: TRANSISTOR AMPLIFIER CIRCUITS

I. Characteristics of the common-base circuit (TM 2.1)

- A. The common-base (CB) circuit configuration uses the base of the transistor as the common reference point and the emitter and collector regions as the input and output connections.



- B. CB circuit characteristics
    1. Relatively high voltage gain
    2. Low current gain (gain less than 1, typically 0.95 to 0.99)

        NOTE: The current gain of a CB circuit is identified by the greek letter alpha (α) and is equal to the change in collector current divided by the change in emitter current.

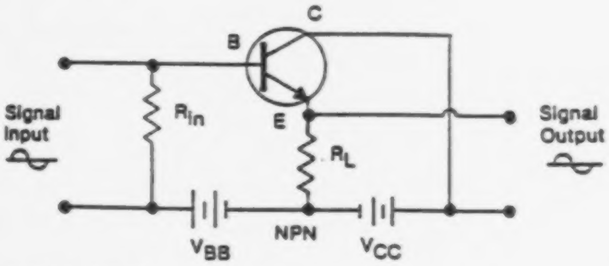
    3. Medium power gain
    4. Low input impedance
    5. High output impedance
- C. The input signal is in-phase with the output signal.

II. Characteristics of the common-collector circuit (TM 2.2)

- A. The common-collector (CC) configuration uses the collector as the common reference point and the base and emitter as the input and output connections.

    NOTE: The common-collector is also known as an emitter follower.

- B. CC configuration characteristics
    1. Low voltage gain
    2. High current gain
    3. Low power gain
    4. High input impedance
    5. Low output impedance

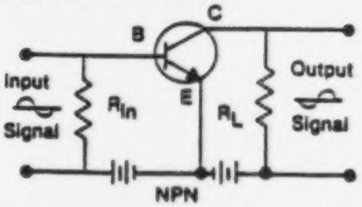


- C. The input signal is in-phase with the output signal.

III. Characteristics of the common-emitter circuit (TM 2.3, HO 2.1)

A. The common-emitter (CE) configuration uses the emitter as the common reference point and the base and collector as input and output connections.

B. CE configuration characteristics



1. Relatively high voltage gain

2. High current gain

NOTE: The current gain of a common-emitter circuit is commonly identified by the greek letter beta (β) and is calculated by dividing the change in collector current by the change in base current.

3. Very high power gain

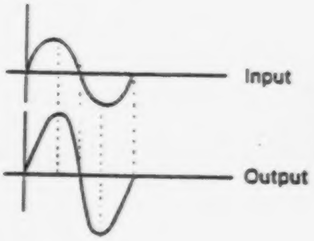
4. Medium input impedance

5. Medium output impedance

C. The input signal is out-of-phase with the output signal.

IV. Classes of operation

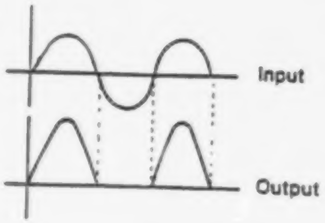
A. A class A operation is an amplifier circuit biased so that the collector current flows during the entire input-signal cycle.



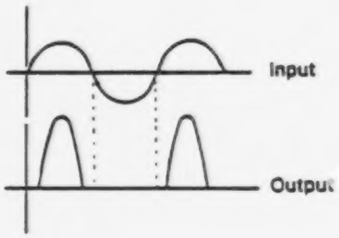
1. A transistor load line can be constructed to determine the operating or Q point of a circuit.

2. The cut-off and saturation points can be determined using a load line and transistor characteristic curves.

B. A class B operation is an amplifier circuit biased so that the collector current flows during half of the input-signal cycle.



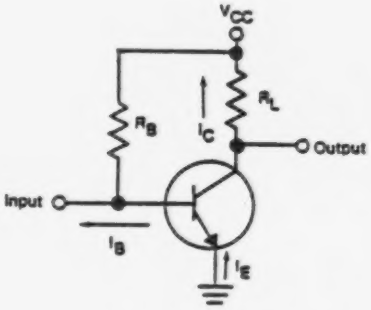
C. A class C operation is an amplifier circuit biased so that the collector current flows for less than half of the input-signal cycle.



V. Transistor biasing techniques

A. Practical transistor circuits are biased using a single voltage source.

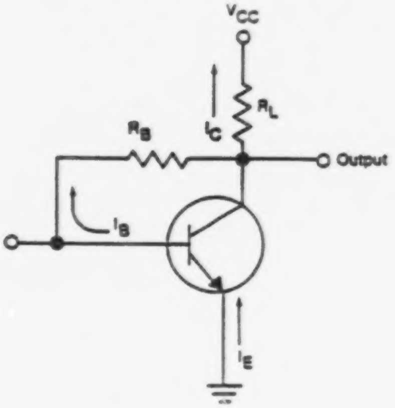
B. Base-biasing is the most simple form of transistor biasing but is not used extensively because of its thermal instability.


V_{CC}
R_B
I_C
R_L
Output
Input
I_B
I_E

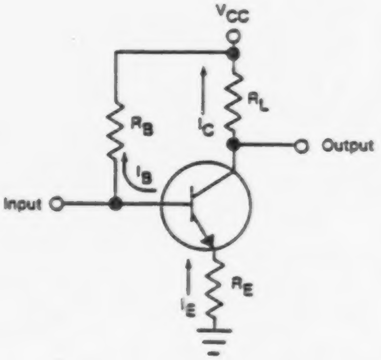
C. Feedback bias can be used to improve the thermal stability of a circuit.

1. Degenerative or negative feedback can be used to counteract changes due to thermal instability.

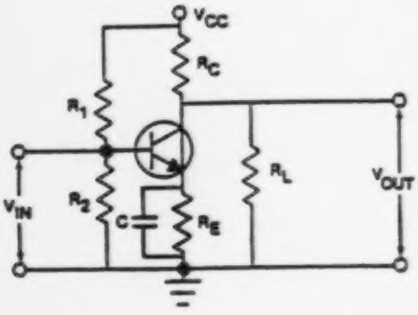
2. Collector feedback provides degenerative feedback.


V_{CC}
R_B
I_C
R_L
Output
I_B
I_E

3. Emitter feedback can be used to provide degenerative feedback.


V_{CC}
R_B
I_C
R_L
Output
Input
I_B
I_E
R_E

D. Voltage divider bias is a widely used type in electronic circuits and provides a great degree of circuit stability.

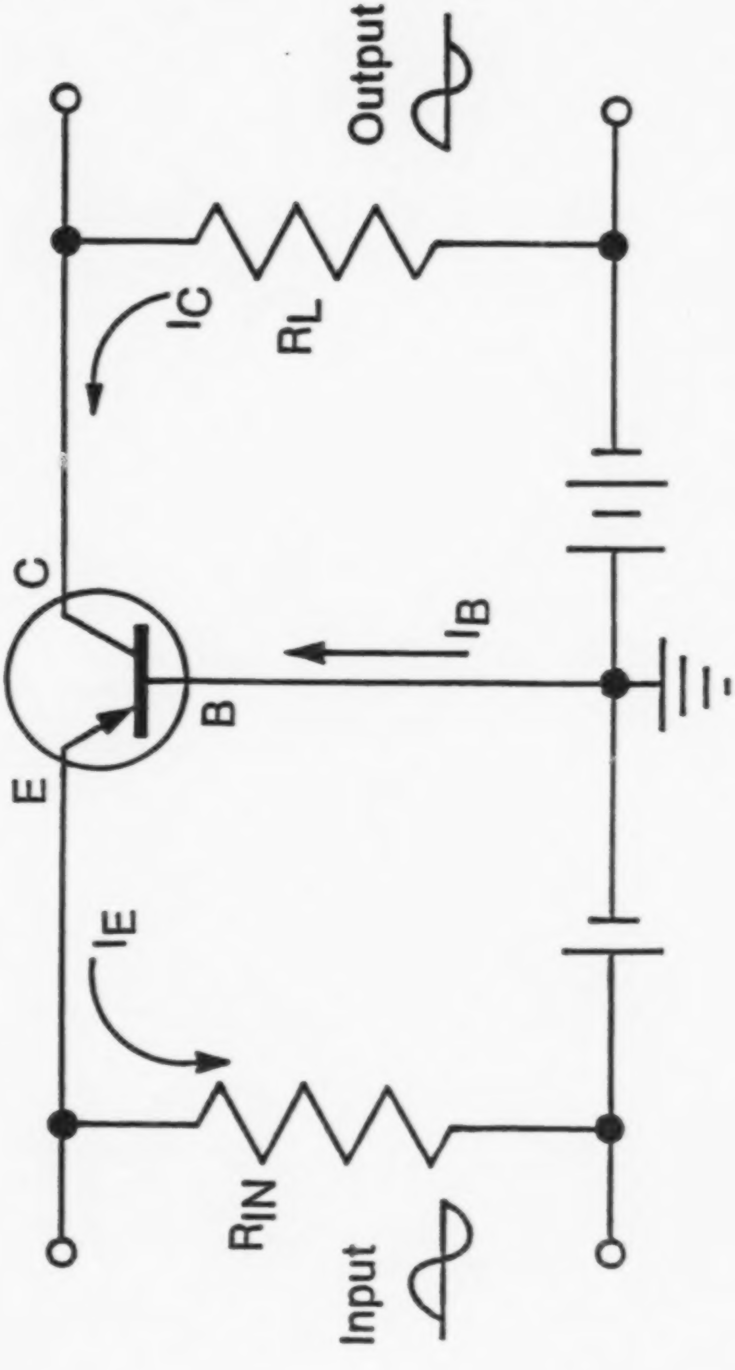


E. "Rule of thumb" characteristics

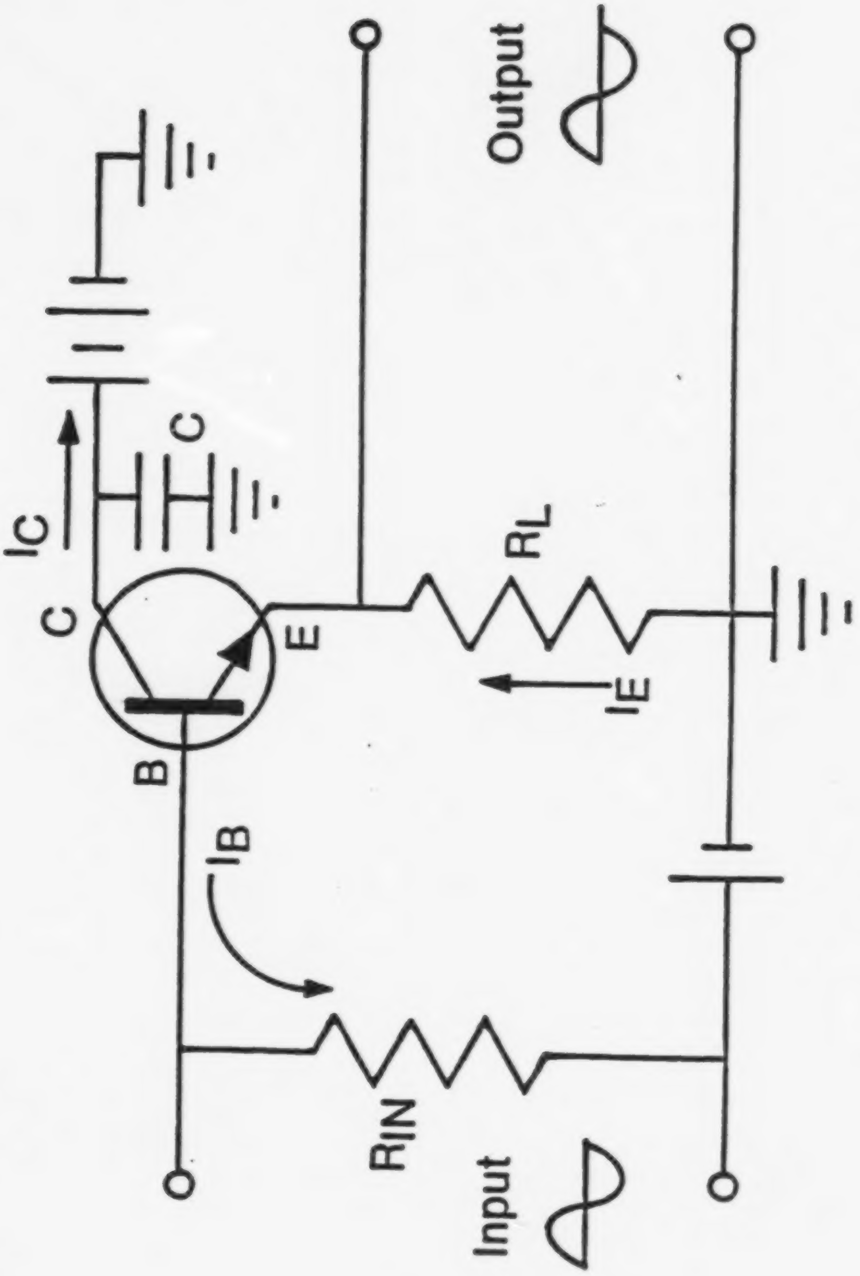
1. R_E will drop about one-tenth V_{CC}.
2. R_2 value is approximately 10 times R_E.
3. R_1 value is approximately nine times R_2.
4. R_1 value is chosen to drop 45% of V_{CC}.
5. C will have an X_C about one-tenth R_E at the lowest operating frequency.

TM 2.1

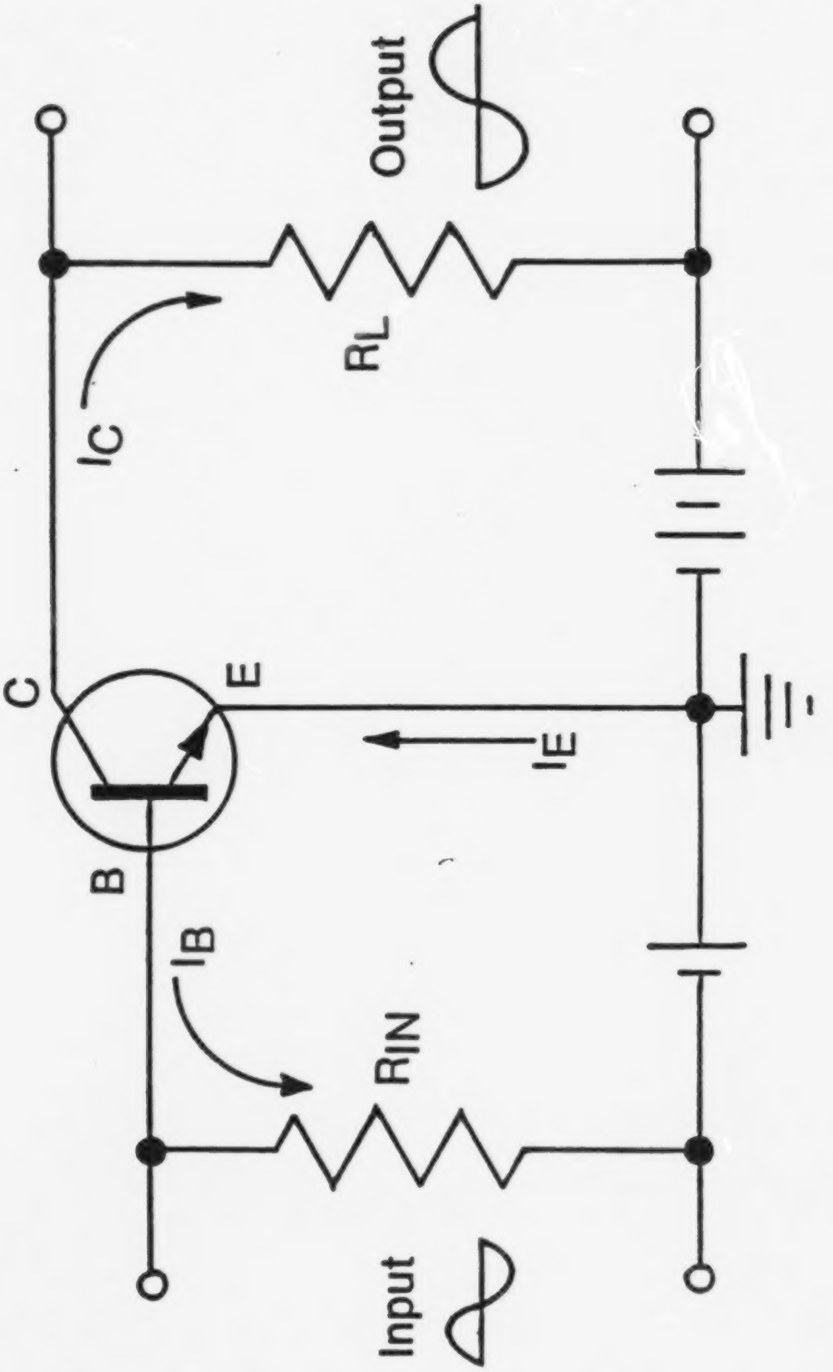
COMMON-BASE AMPLIFIER (PNP) CIRCUIT


Output
R_L
I_C
C
I_B
B
E
I_E
R_{IN}
Input

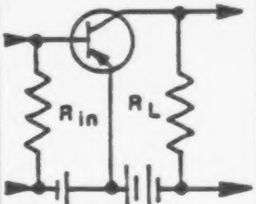
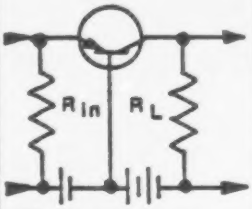
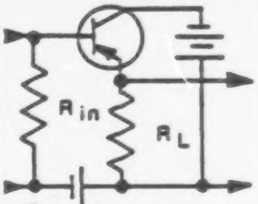
COMMON-COLLECTOR AMPLIFIER (NPN) CIRCUIT


Output
I_C
C
C
R_L
E
I_E
B
I_B
R_{IN}
Input

COMMON-EMITTER AMPLIFIER (NPN) CIRCUIT


Output
R_L
I_C
C
E
I_E
B
I_B
R_IN
Input

COMPARISON OF TRANSISTOR CIRCUIT COMBINATIONS

Characteristics	 Common Emitter	 Common Base	 Common Collector
Voltage Gain $A_e = \frac{E\ out}{E\ in}$	High (300)	High (500)	Low Less Than One
Current Gain $A_i = \frac{I\ in}{I\ out}$	High (50)	Low (0.97)	High (50)
Power Gain $A_p = \frac{P\ out}{P\ in}$	Very High (12,000)	Medium (400)	Low (30)
Input Impedance	Medium (1,000)	Low (60)	High (400,000)
Output Impedance	Medium (50,000)	High (1 M)	Low (100)
Phase Reversal	Yes	No	No

JS 2.1

CONSTRUCT AND TEST A COMMON-EMITTER CIRCUIT

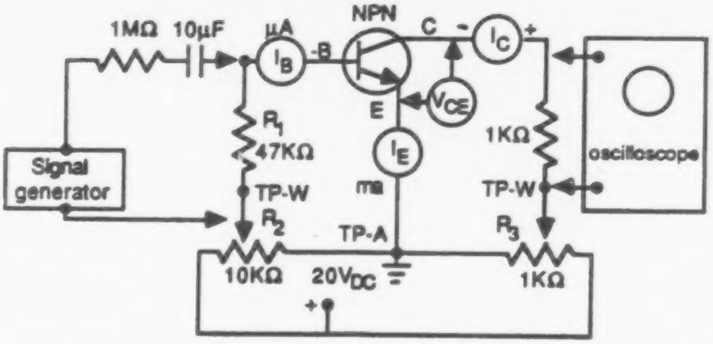
Equipment:

NPN transistor
Ammeters (0-50mA range)
Voltmeter
Oscilloscope
Audio signal generator
Resistors: One each of 1MΩ, 47KΩ, 1KΩ, 10KΩ and 1KΩ potentiometer (use 1/2 watt resistor)
NOTE: Resistor values may vary for your particular transistor.
10µF capacitor
Power supply, 0-20V_{DC}

Procedure:

Evaluation
3 2 1 N

1. Do not turn on power supply at this time. Connect the circuit as shown below. Ask the instructor to approve your circuit wiring. ___ ___ ___ ___



NOTE: If you do not have a microammeter for I_B, insert a 100Ω resistor in series and use a voltmeter to read the voltage drop. Then, compute the current from the voltmeter reading and the value of the resistor.

2. Set the potentiometer to 0Ω between test points A and W. ___ ___ ___ ___
3. Set the power supply for 20V_{DC}. ___ ___ ___ ___
4. Adjust the collector potentiometer R_3 until V_{CE} is 6.0 volts. ___ ___ ___ ___
5. Adjust the base resistor R_2 until the base current, I_B, is 20 microamperes. ___ ___ ___ ___
6. Recheck V_{CE} to see that it has remained at 6.0 volts. Read and record I_C when V_{CE} = 6.0V and I_B = 20µA. ___ ___ ___ ___

NOTE: It may be necessary to readjust R_3 to maintain V_{CE} = 6V and I_a = 20 µA.

Data table

DC measurements

V_{CE}	I_C	I_B	I_E	$\frac{\Delta I_C}{\Delta I_B}$
6.0V		20μA		
6.0V		40μA		

AC measurements

	P-P	RMS
I_{in}		
I_{out}		
V_{ik}		
I_{out}		
V_{1m}		
I_{in}		
A_I		
A_IdB		

7. Using the voltmeter, read and record the base-emitter DC voltage.

8. Increase the base resistor, R_2, until I_B is 40 microamperes.

9. Recheck that V_{CE} = 6.0V; adjust R_3 as needed. Read and record I_C when V_{CE} = 6.0V and I_B = 40 μA.

10. Connect the signal generator across the 47KΩ input resistor and set the output frequency to 1KHz.

11. Turn the signal generator on and adjust the input signal, E_{in}, across the input resistor, R_1, to 10mV rms value.

12. Use the oscilloscope to observe this waveform. Make a sketch of the waveform showing frequency and amplitude.

13. Move the oscilloscope to observe the output voltage across the 1KΩ output resistor.

14. Make a sketch of the output waveform, showing amplitude and frequency. ____ ____ ____ ____

15. Compute and record the output voltage, E_O, in rms. ____ ____ ____ ____

16. Compute the output current, I_{out}, by dividing the output voltage, E_O, by the load resistance, 1KΩ. ____ ____ ____ ____

17. Measure rms voltage across the 1MΩ series resistor. ____ ____ ____ ____

18. Compute and record the input current, I_{in}. ____ ____ ____ ____

19. Calculate the current gain by dividing I_{out} by I_{in} and expressing the answer in dB. ____ ____ ____ ____

20. Return equipment to its proper storage area. ____ ____ ____ ____

Average of above evaluations* ____ ____ ____ ____

*This average is the student's partial evaluation for competencies D4 and D14.

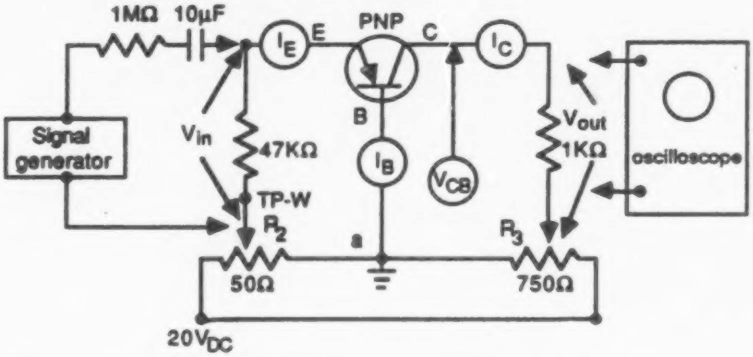
JS 2.2

CONSTRUCT AND TEST A COMMON-BASE CIRCUIT

Equipment:

PNP transistor
Variable power supply (0-20V_{DC})
Oscilloscope
Audio signal generator
Voltmeter
Microammeter (or multimeter)
Two milliammeters (or multimeter)
Resistors: One each of 1KΩ, 47KΩ and 1MΩ (use 1/2 watt resistor)
10μF capacitor
Potentiometers: 50Ω, 1W and 750 1W

Procedure:	Evaluation 3	 2	 1	 N
1. Do not turn on power supply at this time. Connect the circuit as shown below. Ask the instructor to check your circuit wiring.	—	—	—	—



1MΩ
10μF
I_E
E
PNP
C
I_C
Signal generator
V_{in}
47KΩ
B
I_B
V_{CB}
V_{out}
1KΩ
oscilloscope
TP-W
R_2
a
R_3
50Ω
750Ω
20V_{DC}

	3	2	1	N
2. Adjust potentiometer R_2 until the resistance between test point A and W reads 0Ω.	—	—	—	—
3. Turn on power supply and set for 20 volts.	—	—	—	—
4. Adjust potentiometer R_3 until V_{CB} reads 5.8 volts.	—	—	—	—
5. Adjust potentiometer R_2 until the collector current reads 25mA.	—	—	—	—

6. Read and record I_C, I_B and I_E. ____ ____ ____ ____

Data table

DC measurements

(NOTE: △ indicates "change in.")

	VCE	I_C	I_B	I_E	$\frac{\Delta I_C}{\Delta I_B}$
Test 1 **(Step H)**	25μA				
Test 2 **(Step J)**					

AC measurements

	P-P	RMS
e_{in}		
V_{in}		
i_{in}		
$e_{o(Vlx)}$		
I_o		
A_v		
A_vdB		

7. Adjust potentiometer R_2 to obtain a 20 microampere increase in I_B. ____ ____ ____ ____

8. Measure and record I_C, I_B and I_E. ____ ____ ____ ____

9. Measure V_{EB} with the voltmeter. ____ ____ ____ ____

10. State whether the transistor is germanium or silicon. ____ ____ ____ ____

11. Connect the signal generator across to 47KΩ input resistor. ____ ____ ____ ____

12. Set the signal generator for 1KHz. ____ ____ ____ ____

13. Adjust the signal generator until the voltage across the 47KΩ input resistor reads 10mV rms. ____ ____ ____ ____

14. Using the oscilloscope, observe the waveform of the voltage E_{in} across the 47KΩ input resistor. Sketch the waveform of E_{in} showing frequency and amplitude. ____ ____ ____ ____

15. Measure the rms voltage across the 1 MΩ resistor and compute the rms input current, I_{in}. ____ ____ ____ ____

16. Using the oscilloscope, observe the waveform of the voltage E_o across the 1KΩ load resistor. Sketch the waveform of E_o showing amplitude and frequency. ____ ____ ____ ____

17. Calculate the rms value of E_o. ____ ____ ____ ____

18. Calculate the rms value of the output current, I_o. ____ ____ ____ ____

19. Calculate the voltage gain of the circuit. Express the voltage gain of the circuit in db. ____ ____ ____ ____

NOTE: Remember to convert peak-to-peak voltage readings from scope to rms value.

20. Return equipment to its proper storage area. ____ ____ ____ ____

Average of above evaluations* ____ ____ ____ ____

*This average is the student's partial evaluation for competencies D4 and D14.

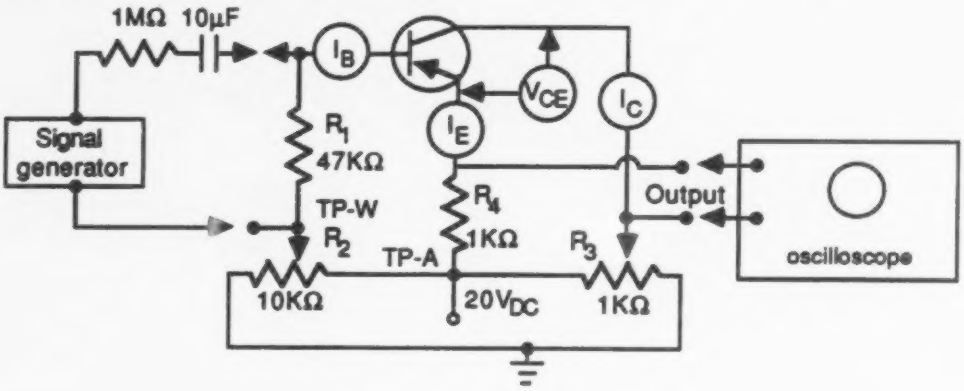
JS 2.3

CONSTRUCT AND TEST A COMMON-COLLECTOR CIRCUIT

Equipment:

Variable power supply (0-20V)
PNP transistor
Oscilloscope
Signal generator
Voltmeter
10μF capacitor
Resistors: One each of 47KΩ, 1KΩ and 1MΩ (use 1/2 watt resistor)
Microammeter (multimeter)
Two milliammeters (multimeters)
Potentiometers: one 10KΩ and one 1KΩ (use 1 watt potentiometer)

Procedure:	Evaluation 3	2	1	N
1. Do not turn on power supply at this time. Connect circuit as shown. Ask the instructor to approve your circuit wiring.	___	___	___	___


1MΩ
10μF
I_B
V_{CE}
I_C
I_E
Signal generator
R_1
47KΩ
TP-W
R_2
TP-A
R_4
1KΩ
R_3
Output
oscilloscope
10KΩ
$20V_{DC}$
1KΩ

Procedure:	3	2	1	N
2. Set potentiometer R_2 to 0Ω between test points A and W.	___	___	___	___
3. Set the power supply to 20 volts.	___	___	___	___
4. Adjust potentiometer R_2 until I_B reads 20μA.	___	___	___	___
5. Adjust potentiometer R_3 until V_{CE}, as measured by the voltmeter, reads 6 volts.	___	___	___	___
6. Measure and record I_E, I_B and I_C.	___	___	___	___

Data table

DC measurements

	I_E	I_B	I_C	V_{BE}
V_{CE} = 6v		20μA		
V_{CE} =		40μA		
A_I =				

AC measurements

	P-P	rms
V_{in}		
I_{in} calculated		
V_{out}		
I_{out}		
A dB= Cal.		
A_IdB cal.		
A_pdB cal.		

7. Adjust potentiometer R_2 until I_B reads 40μA. — — — —
8. Measure and record I_E, I_B and I_C. — — — —
9. Measure V_{BE} with the voltmeter and determine if the transistor is germanium or silicon. — — — —
10. Connect the signal generator across the input resistor (47ΩK). — — — —
11. Connect the voltmeter across the 47 KΩ resistor and adjust the signal generator at 1KHz until the voltmeter reads 10mV rms. — — — —
12. Read the rms voltage across the 1MΩ resistor. — — — —

13. Calculate the input current. — — — —

14. Sketch the waveform of the input voltage showing both amplitude and frequency, as displayed on the oscilloscope. — — — —

15. Sketch the observed output waveform across the 1KΩ load resistor and calculate the rms output voltage. — — — —

16. Calculate the rms value of the output current, I_o. — — — —

17. Calculate the circuit's power gain and express the value in db. — — — —

18. Return equipment to its proper storage area. — — — —

Average of above evaluations* — — — —

*This average is the student's final evaluation for competency D14 and partial evaluation for D4.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT VIII: BIPOLAR JUNCTION TRANSISTOR (BJT)

UNIT TEST

Choose the option which best answers the question or completes the statement.

____ 1. Which of the following statements about bipolar transistors is false?

a. A bipolar transistor is a three-terminal, current-controlled semiconductor device containing two P-N junctions.
b. The bipolar transistor consists of three sections called the emitter, base and collector.
c. Bipolar transistors are of two major types: NPN and PNP.
d. Bipolar transistors are used primarily for switching and to increase the amplitude or strength of electronic signals.
e. Bipolar transistors are packaged in a specially designed container primarily to improve their appearance.

____ 2. Which of the following statements about common-base circuits is false?

a. The CB circuit configuration uses the base as the common reference point. The emitter and collector regions serve as input and output connections.
b. The CB circuit has a relatively high voltage gain.
c. The CB has a low current gain (less than 1, typically 0.95-0.99).
d. CB circuits have a medium power gain.
e. CB circuits have a high input impedance.

____ 3. Select the false common-collector statement from the following.

a. The CC configuration uses the collector as the common reference point. The base and emitter serve as input and output connections.
b. The CC has a low voltage gain.
c. CCs have a high current gain.
d. The CC has a high power gain.
e. The CC has a high input impedance.

____ 4. Which statement is false?

a. The common-emitter circuit (CE) has a relatively high voltage gain.
b. The CE has a high current gain.
c. CE circuits have a medium value of input impedance.
d. CE circuits have a medium value of output impedance.
e. The input signal is in-phase with the output signal.

____ 5. Which class of amplifier circuit is biased so that the collector current flows during half of the input-signal cycle?

a. Class A
b. Class B
c. Class C
d. Class D
e. Class E

___ 6. Which class of amplifier circuit is biased so that the CC flows for less than half of the input-signal cycle?

a. Class A
b. Class B
c. Class C
d. Class D
e. Class E

___ 7. Which class of amplifier circuit is biased so that the CC flows during the entire input-signal cycle?

a. Class A
b. Class B
c. Class C
d. Class D
e. Class E

___ 8. Which type of biasing technique is widely used in electronic circuits and provides a great deal of stability?

a. Voltage divider
b. Single voltage source
c. Feedback bias
d. Base-biasing
e. Self-biasing

___ 9. Which describes a component made of one functional element (as compared to an I.C. device of many elements)?

a. Analog device
b. Collector
c. Discrete device
d. Linear device
e. Amplifier

Match the following transistor characteristics to the proper type.

____ 10. Most heavily doped section of transistor

____ 11. Constructed very narrowly to improve transistor frequency response

____ 12. Indicated schematically by a diagonal line

____ 13. Carry large amount of total current into or out of transistor

____ 14. Indicated schematically by a perpendicular line

____ 15. Have most majority current carriers

____ 16. Indicated schematically by an arrowhead

____ 17. Control current flow through transistor

____ 18. Often connected to metal case of transistor

____ 19. Carry all current that passes into or out of transistor

____ 20. Contain material opposite other two sections of transistor

____ 21. Carry only small portion of current passing into or out of transistor

a. Amplifier

b. Base

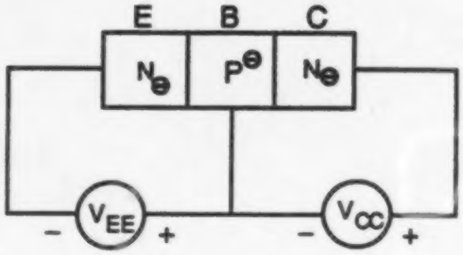
c. Collector

d. Drain

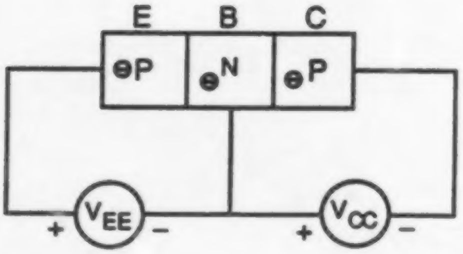
e. Emitter

Draw arrows to indicate the direction of current flow in the following transistors.

22.



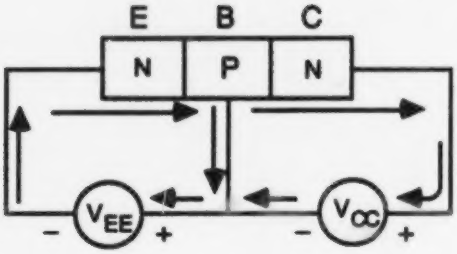
23.



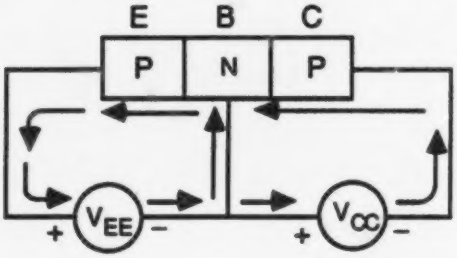
ANSWERS TO UNIT TEST (D3)

1. e
2. e
3. d
4. e
5. b
6. c
7. a
8. a
9. c
10. e
11. b
12. c
13. c
14. b
15. e
16. e
17. b
18. c
19. e
20. b
21. b

22.


E
B
C
N
P
N
V_EE
V_CC
−
+
−
+

23.


E
B
C
P
N
P
V_EE
V_CC
+
−
+
−

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT IX: MULTI-STAGE AMPLIFIERS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to discuss components and characteristics of multi-stage amplifiers. This knowledge will be demonstrated by achieving the specified score on the job sheets and unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Match terms concerning multi-stage amplifiers with definitions.

1.2 Identify multi-stage amplifier characteristics.

1.3 Identify true statements about amplifier components.

1.4 Distinguish between true and false statements about amplifier coupling methods. (competencies E1 and E7)

1.5 Identify true statements about tuned amplifiers.

1.6 Test operation of two-stage amplifier. (competency D4, partial E4, JS 1.1)

1.7 Test operation of push-pull with capacitor coupling. (competency D4, partial E4, JS 1.2)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT IX: MULTI-STAGE AMPLIFIERS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

1. Lesson 1: MULTI-STAGE AMPLIFIERS

   a. Information outline

   b. Transparency masters

      TM 1.1: Coupling
      TM 1.2: Transformer coupling

   c. Job sheets

      JS 1.1: Test operation of two-stage amplifier
      JS 1.2: Test operation of push-pull with capacitor coupling

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Grob, Bernard. Basic Electronics. 5th ed. New York: McGraw-Hill, 1984.

2. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.

3. Hughes, Fredrick W. Basic Electronics: Theory and Experimentation. Englewood Cliffs, NJ: Prentice-Hall, 1984.

4. Malvino, Albert Paul. Semiconductor Circuit Approximations. 4th ed. New York: McGraw-Hill Book Co., 1985.

5. Schuler, Charles A. Electronics: Principles and Applications. New York: McGraw-Hill, 1979.

6. Weir, Walter. Electronic Circuit Fundamentals. Englewood Cliffs, NJ: Prentice-Hall, 1987.

B. Curriculum guides

1. Hartman, Lonnie. Basic Electronics. Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1987.
2. Vorderstrasse, Ron. General Electronics Technician. Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1987.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT IX: MULTI-STAGE AMPLIFIERS

LESSON 1: MULTI-STAGE AMPLIFIERS

I. Terms and definitions

   A. Cascade--connection of two or more amplifier stages together where the output of one circuit becomes the input of the next one

   B. Complementary symmetry--circuit using two transistors that complement each other

   C. Coupling--method of connecting amplifier stages for an efficient transfer of power or signal from one stage to another

   D. Darlington pair--circuit contained in a single package using two transistors directly coupled

   E. Driver--stage that receives signal from pre-amplifier and amplifies the signal for the final amplifier

   F. Final amplifier--last stage in an amplifier

   G. Hum--unwanted signals being amplified

   H. Noise--60-cycle interference in an amplifier

   I. Pre-amplifier--stage that receives a very low input signal and amplifies the signal for the next stage

   J. Push-pull--circuit using two NPN amplifiers

   K. Quasi-complementary--circuit that uses extra NPN transistors to avoid using a PNP

   L. Stage--each amplifier in a multi-stage amplifier

   M. Totem pole--circuit using two stacked transistors

II. Multi-stage amplifier characteristics

   A. A signal may need amplification in order to drive or operate an output device such as a speaker.

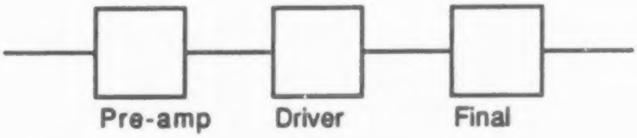
   B. Many applications require more than one amplifier.

      1. Each amplifier is called a stage.

      2. Several stages connected together form a multi-stage amplifier.

      3. The last stage of amplification is called the final amplifier or final.

      4. Preceding stages are called pre-amps and drivers.



5. The stages can use transistors as amplifiers.

III. Pre-amplifier (pre-amp)

A. Low-level input from the signal source

1. Output from the pre-amp is large enough to drive the input of the next stage.

2. Pre-amps must have very low hum and noise.

B. Signal to drive the finals provided by the driver

C. Signal to drive the output device provided by the output stage (final)

D. Finals made up of one or more transistors

E. Darlington pair

1. Two emitter-followers in cascade

2. Voltage gain of less than one

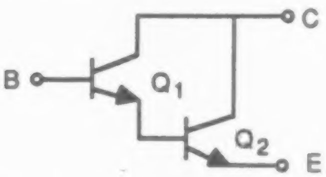
3. High current gain

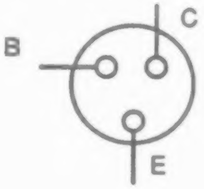
4. High input impedance

5. Low output impedance

6. No phase inversion

7. Circuit contained in a single package with three leads





F. Totem-pole output

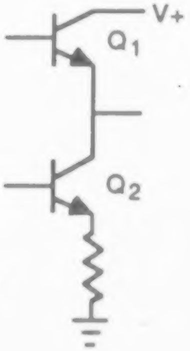
1. Circuit consisting of two stacked transistors

2. Used in digital electronics

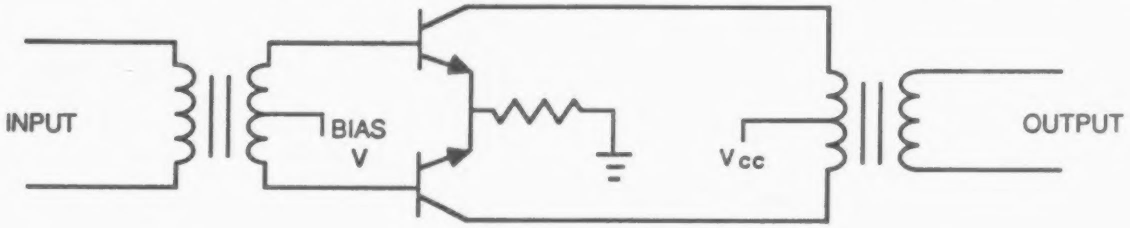
G. Push-pull amplifier

1. These amplifiers have two operating transistors.

2. While the current is increasing in one stage, the current is decreasing in the other.



3. Push-pull amplifiers are used in audio circuits for low distortion and high power output.


INPUT
BIAS
V
Vcc
OUTPUT

4. A phase-splitting device (e.g. a transformer) is necessary to drive both transistors.

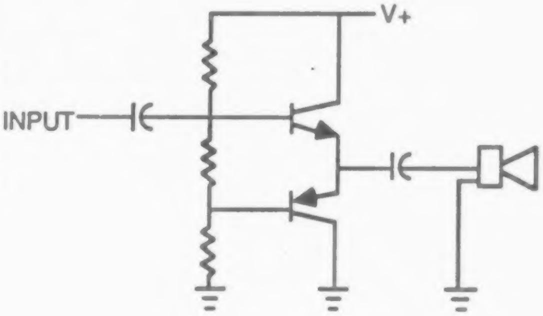
5. A center-tapped transformer is required in the output circuit.

H. Complementary symmetry

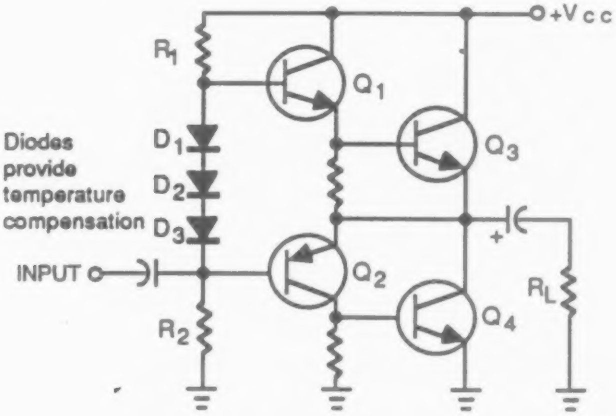
1. PNP and NPN transistors in a stacked configuration

2. Since NPN and PNP transistors complement each other, no phase-splitting input is required.

3. An output transformer is not used.



I. Quasi-complementary


+Vcc
R1
Q1
Q3
Diodes provide temperature compensation
D1
D2
D3
+
INPUT
Q2
RL
R2
Q4

1. Driver stages are NPN and PNP transistors.

2. Output stages are NPN transistors.

3. Using quasi-complimentary pre-amps eliminates the need for the higher-cost PNP output transistor.

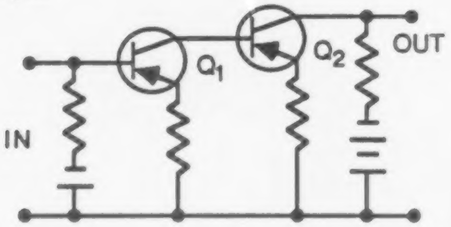
IV. Methods of coupling to transfer the signal from one stage to another **(TM 1.1, 1.2)**

A. Direct coupling is generally used to amplify low frequency signals.

1. Used to couple only a few stages

2. Direct-coupled amplifiers are noisy.

Example: Darlington pair



B. Capacitor or RC (resistance-capacitor) coupling is often used when amplifying AC signals.

1. Capacitor coupling will block any DC voltage from bias voltage or any DC component of the signal.

2. The capacitor is selected for low reactance to the signal frequency.

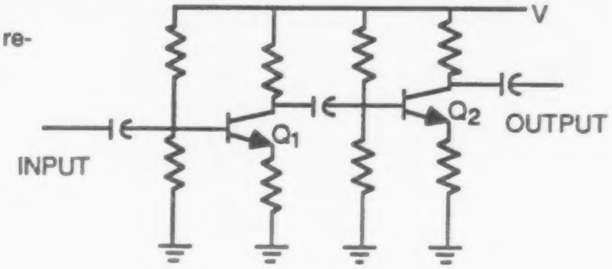
3. This method of coupling has:

   a. Broad frequency response

   b. Small size

   c. Low cost

   d. DC isolation



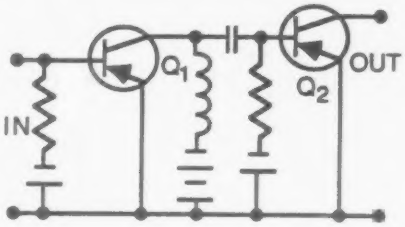
C. Impedance (LC) coupling uses an inductor and capacitor to connect amplifier stages.

1. Large output at high frequencies

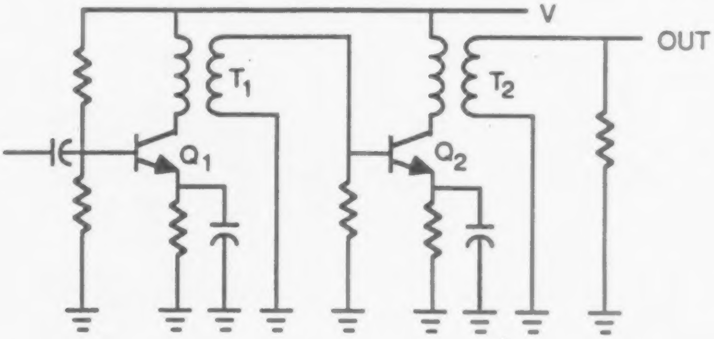
2. Narrow frequency response

D. Transformer coupling is used mainly for impedance matching.

1. Transformer coupling is not used for audio circuits because of cost and size, except for output or high-power applications.



2. RF (radio frequency) amplifiers still use this method of coupling.



3. RF transformers are small and less expensive, as compared to audio transformers.

4. More gain is possible with transformer couplings.

5. At high frequencies, the inductive reactance of the transformer can cause problems.

V. Tuned amplifier

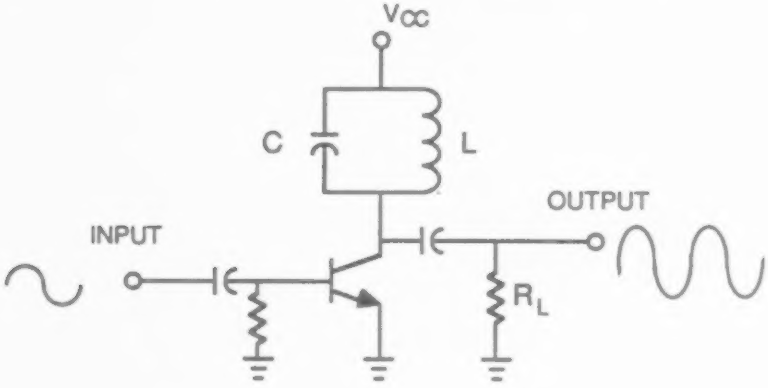
A. Tuned amplifiers are normally used in RF (radio frequency) applications (radio and TV).

B. The collector output is a series of narrow pulses.

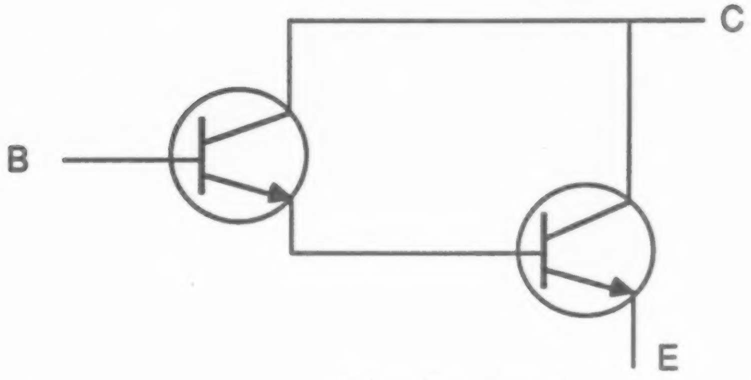
C. The distortion on the output is unacceptable for use in audio circuits.

D. The coil (L) and capacitor (C) valves determine the resonant frequency.

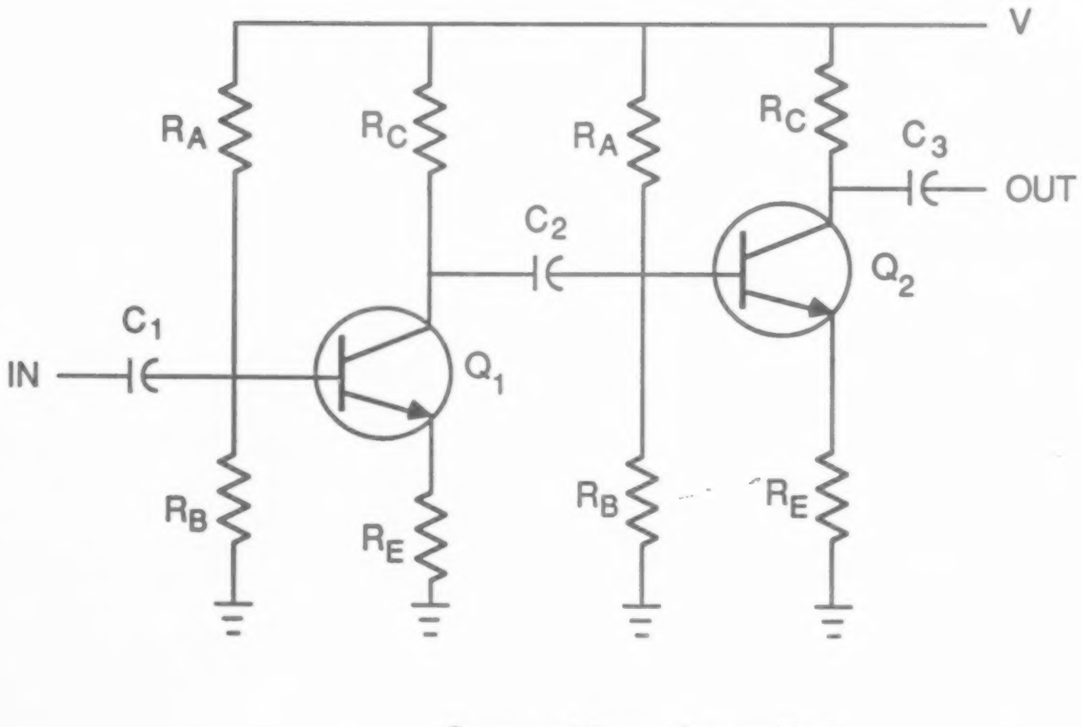
E. The L and C form a tank circuit that will filter all frequencies except the resonant frequency.



COUPLING

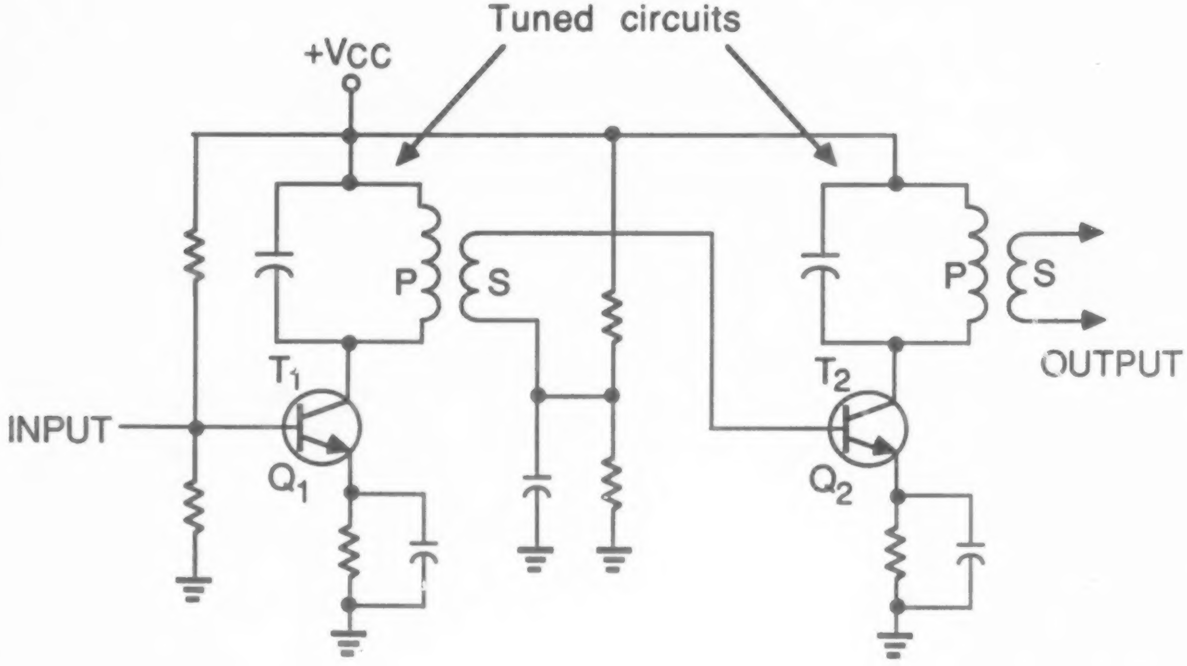


(Darlington)
Direct Coupling


V
R_A
R_C
R_A
R_C
C_3
OUT
C_2
Q_2
C_1
IN
Q_1
R_B
R_E
R_B
R_E

Capacitive Coupling

TRANSFORMER COUPLING


Tuned circuits
+VCC
P
S
P
S
OUTPUT
T_1
T_2
INPUT
Q_1
Q_2

Tuned RF amplifier

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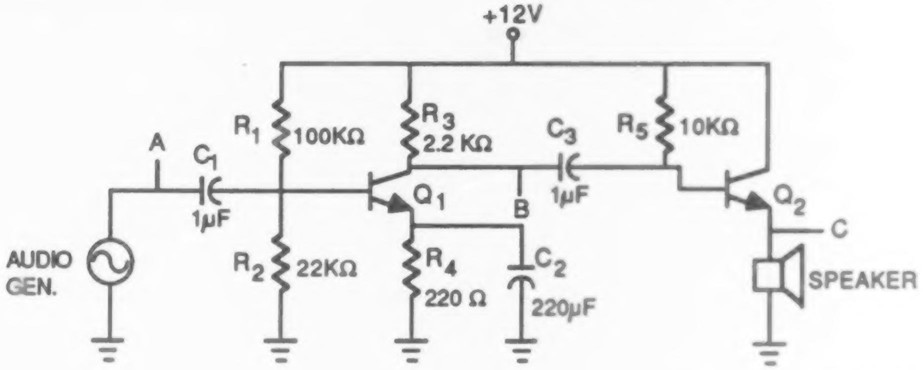
TEST OPERATION OF TWO-STAGE AMPLIFIER

Equipment:

Power supply	Resistors:	220Ω, 1/2 W
Oscilloscope		2.2KΩ, 1/2 W
Multimeter		10KΩ, 1/2 W
Audio generator		22K, 1/2 W
Transistors: 2N2222, 2N3055 (1 each)		100K, 1/2 W
8Ω loudspeaker	Capacitors:	1μF, 15 V
		220μF, 15 V



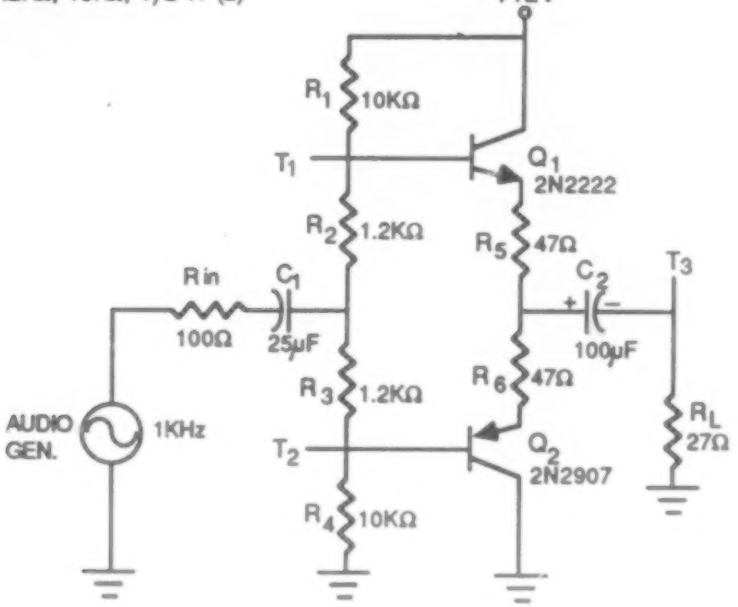
Procedure:	Evaluation 3	2	1	N
1. Construct circuit as shown in the figure above. Do not apply power.				
2. Check circuit for correct construction.				
3. Apply power. With a voltmeter, measure and record voltages of Q_1 and Q_2 with no signal applied at the base, emitter and collector.				
4. Apply signal of $0.5V_{p.p.}$, 1 KHz sine wave. Measure and record the voltages at the base, emitter and collector of Q_1 and Q_2 with a voltmeter.				
5. Measure signal at point A, point B and point C with an oscilloscope. Record measurements.				
6. Return equipment and materials to storage area.				
Average of above evaluations*				

*This average is the student's partial evaluation for competencies D4 and E4.

TEST OPERATION OF PUSH-PULL WITH CAPACITIVE COUPLING

Equipment:

Oscilloscope
Multimeter
Audio generator
Power supply
Transistors: 2N2222, 2N2907
Capacitors: 25μF, 25 V
100μF, 25 V
Resistors: 27Ω, 100Ω, 1/2 W (2)
47Ω, 1.2KΩ, 10KΩ, 1/2 W (2)


+12V
R1 10KΩ
T1
Q1 2N2222
R2 1.2KΩ
R5 47Ω
Rin 100Ω
C1 25μF
C2 100μF
+
−
T3
R3 1.2KΩ
R6 47Ω
AUDIO GEN.
1KHz
T2
Q2 2N2907
RL 27Ω
R4 10KΩ

Procedure:	Evaluation 3	2	1	N
1. Construct circuit as shown in the figure above. Do not apply power.	___	___	___	___
2. Check circuit for correct construction.	___	___	___	___
3. Turn on power. With oscilloscope, measure waveform at T_1, T_2 and T_3.	___	___	___	___
4. Draw waveform observed at T_1, T_2 and T_3.	___	___	___	___

5. Measure voltage of Q_1 and Q_2 at the base, emitter and collector. Record voltage readings.	___	___	___	___
6. Remove signal. Measure and record voltage on Q_1 and Q_2 at base, emitter and collector.	___	___	___	___
7. Return materials and equipment to storage area.	___	___	___	___
Average of above evaluations*	___	___	___	___

*This average is the student's partial evaluation for competency E4 and concludes the student's evaluation for competency D4.

SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT IX: MULTI-STAGE AMPLIFIERS

UNIT TEST

Identify true statements with an "a" and false statements with a "b".

____ 1. Finals can be made up of one or more transistors.

____ 2. A totem pole output consists of two stacked transistors.

____ 3. An audio push-pull amplifier has high distortion and low output.

____ 4. Direct coupling is used to amplify low-frequency signals.

____ 5. Capacitor coupling is used to block AC signals that distort the DC bias.

____ 6. Transformer coupling is used for impedance matching.

____ 7. A transistor can be used as an amplifier stage.

____ 8. In a multi-stage amplifier, each amplifier is called a stage.

Match terms with appropriate definitions.

____ 9. To connect two or more amplifier stages together

____ 10. Circuit using two transistors that complement each other

____ 11. Circuit using two stacked transistors

____ 12. Method of connecting amplifier stages for an efficient transfer of power

____ 13. Stage that receives signal from the pre-amplifier and amplifies the signal for the final amplifier

____ 14. Last stage in amplifier

____ 15. Circuit contained in a single package using two transistors that are direct coupled

____ 16. Stage that receives a very low input signal and amplifies the signal for the next stage

____ 17. Each amplifier in a multi-stage amplifier

____ 18. Circuit using two NPN amplifiers

a. Cascade

b. Complementary symmetry

c. Coupling

d. Darlington pair

e. Driver

ab. Final amplifier

ac. Pre-amplifier

ad. Push-pull

ae. Quasi-complementary

bc. Stage

bd. Totem pole

ANSWERS TO UNIT TEST

1.	a	(E1)
2.	a	(E1)
3.	b	(E1, E4)
4.	a	(E7)
5.	b	(E7)
6.	a	(E7)
7.	a	(E1)
8.	a	(E1)
9.	a	(E7)
10.	b	(E1)
11.	bd	(E1)
12.	c	(E7)
13.	e	(E1)
14.	ab	(E1)
15.	d	(E1)
16.	ac	(E1, E7)
17.	bc	(E1)
18.	ad	(E1)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT X: LINEAR INTEGRATED CIRCUITS

UNIT OBJECTIVE

After completion of this unit, the student should be able to apply theoretical linear I.C. knowledge to construct and test various types of amplifiers. This knowledge will be evidenced by achieving the specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student will be able to:

1.1 Match terms related to linear integrated amplifier circuits with their definitions.

1.2 Identify differential amplifier circuits.

1.3 Describe integrated circuit construction.

1.4 Explain maximum ratings of an operational amplifier.

1.5 Describe input and output operational amplifier parameters.

1.6 Describe dynamic parameters of the op amp.

1.7 List operational characteristics of the op amp.

1.8 Describe and identify characteristics of the inverting amplifier.

1.9 Describe and identify the characteristics of the non-inverting amplifier.

1.10 State the relationship between gain, bandwidth and feedback in an op amp. (competency E3)

1.11 Demonstrate the ability to: (partial competencies E3, E6 and E8)

   a. Construct and test an inverting amplifier. (JS 1.1)
   b. Construct and test a non-inverting amplifier. (JS 1.2)
   c. Construct and test a differential amplifier. (JS 1.3)
   d. Construct and test a DC summing amplifier. (JS 1.4)

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MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT X: LINEAR INTEGRATED CIRCUITS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

  1. Lesson 1: LINEAR INTEGRATED AMPLIFIER CIRCUITS

    a. Transparency masters

      TM 1.1: Differential amplifier circuit
      TM 1.2: Operational amplifier
      TM 1.3: Comparator
      TM 1.4: Inverting amplifier
      TM 1.5: Non-inverting amplifier
      TM 1.6: Summing amplifier (mixer)

    b. Handout

      HO 1.1: Gain vs. bandwidth

    c. Assignment sheet

      AS 1.1: Calculate closed-loop gain and output voltage

    d. Answers to assignment sheet

    e. Job sheets

      JS 1.1: Construct and test an inverting amplifier
      JS 1.2: Construct and test a non-inverting amplifier
      JS 1.3: Construct and test a differential amplifier
      JS 1.4: Construct and test a DC summing amplifier

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

  1. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.

  2. Malvino, Albert Paul. Electronic Principles. New York: McGraw-Hill Book Co., 1988.

3. Vorderstrasse, Ron. General Electronics Technician. Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1987.

NOTES TO THE INSTRUCTOR

A. Suggested supplemental material

1. Mims, Forrest M. III. Engineer's Mini-Notebook: Op Amps. Fort Worth, Texas: Radio Shack, a division of Tandy Corp., 1986.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT X: LINEAR INTEGRATED CIRCUITS

LESSON 1: LINEAR INTEGRATED AMPLIFIER CIRCUITS

I. Terms and definitions

   A. Active device--component in a circuit which has gain or which directs the flow of current

   B. Analog signal--DC or AC current or voltage that varies smoothly or continuously

   C. Closed-loop operation--application of an operational amplifier circuit that uses external feedback

   D. Common-mode signal--signal voltages that are simultaneously applied to both inputs of a differential amplifier

   E. Comparator--circuit which compares two inputs and produces an output that is a function of the differences

   F. Crosstalk--interference due to cross-coupling between adjacent circuits or to intermodulation of two or more carrier channels

   G. DC offset voltage--small output voltage in practical op amp circuits that is a result of bias currents in the circuits

   H. Differential amplifier--circuit that amplifies the difference between two inputs; the input stage of an op amp

   I. Feedback--coupling of voltage from the output of an amplifier back to its input

   J. Gain bandwidth product--equal to the unity-gain frequency of an op amp bandwidth of a specific circuit. It is equal to the product of gain times.

   K. Integrated circuit--complete electronic circuit that is fabricated on a single chip of silicon

   L. Linear I.C.--classification of integrated circuits used for analog amplification purposes

   M. Monolithic I.C.--integrated circuit fabricated from a single chip of semi-conductor material, usually silicon

   N. Open-loop operation--application of an operational amplifier circuit that uses no external feedback

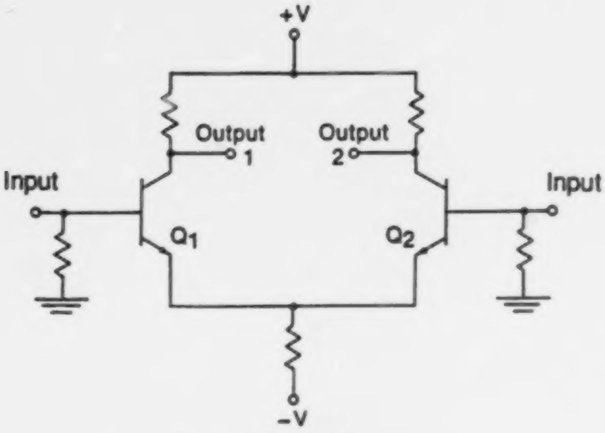
   O. Operational amplifier (op amp)--solid-state I.C. amplifier with very high gain and differential inputs; uses external feedback to control its gain

II. Fundamentals of differential amplifier circuits (TM 1.1)

   A. A basic differential amplifier circuit has two input terminals and two output terminals.

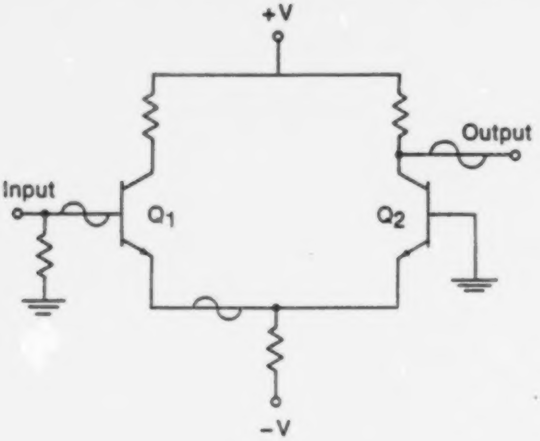
      1. An input can be applied to either or both bases.

      2. An output can be taken from either collector with respect to ground or between the two collectors.



Basic differential amp

B. The simplest connection is the single-input, single-output connection.



Differential amp

1. The output signal is in phase with the input.

2. Overall voltage gain is approximately the same as that of a common-base amplifier.

   NOTE: The base of Q_2 is tied to ground.

3. The amplifier works for both AC and DC signals.

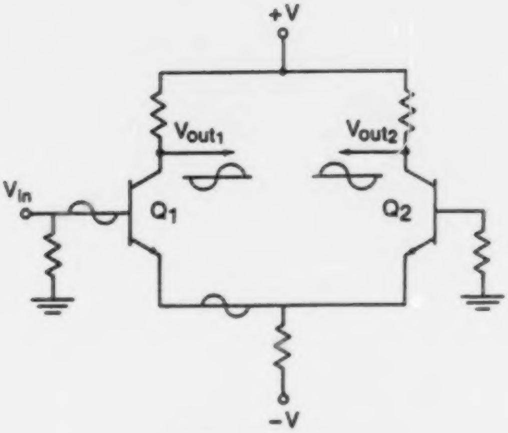
C. The single-input, differential-output has one input terminal and two output terminals.

1. One output is in phase with the input; the other is 180° out of phase with the input.

2. A load can be connected between either of the output terminals and ground.

3. The outputs are of equal amplitude but of opposite phase.

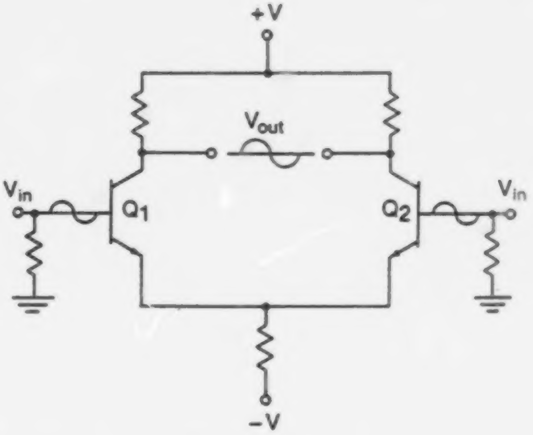
4. The apparent gain of the stage can be doubled by connecting the load between the two output terminals.



Differential amp

D. The differential-input, differential-output circuit has two input terminals and two output terminals.

1. The circuit amplifies the difference between the two input signals.
2. V_{out} is equal to $V_{in}1$ minus $V_{in}2$ times the gain of the amplifier. ($V_{out} = A[V_{in}1 - V_{in}2]$)
3. Outputs are of equal amplitude but of opposite phase.
4. The apparent gain of the stage can be doubled by connecting the load between the two output terminals.



Differential amp

E. The differential amplifier will amplify differential signals and reject common-mode signals (noise and unwanted frequencies of the same phase as the inputs).

F. A differential amplifier's ability is expressed as a ratio of the difference gain to common-mode gain and is called the common-mode rejection ratio (CMRR).

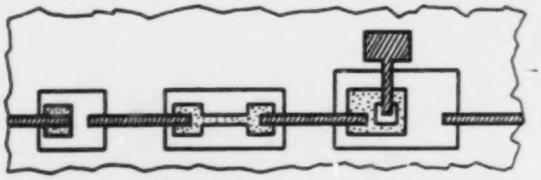
G. The differential amplifier is easily adaptable for application in integrated circuits and is used as a basic concept in a great number of linear integrated circuits.

III. Integrated circuit construction

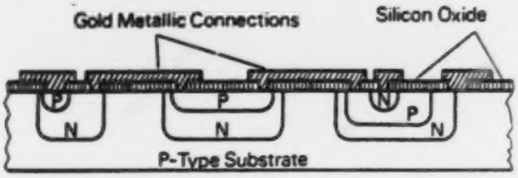
A. Integrated circuits (I.C.s) are classified as monolithic, thin-film, thick-film and hybrid integrated devices.

B. The monolithic I.C. is a complete circuit including active and passive devices. All interconnections are fabricated through a diffusion process on a single piece of semiconductor material.

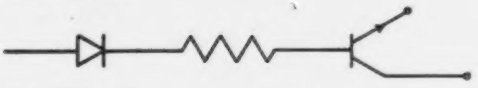
C. Both thin- and thick-filmed I.C.s are used.



Top View (oxide omitted)


Gold Metallic Connections
Silicon Oxide
P
N
P
N
N
P
N
P-Type Substrate

Cross Section



Schematic

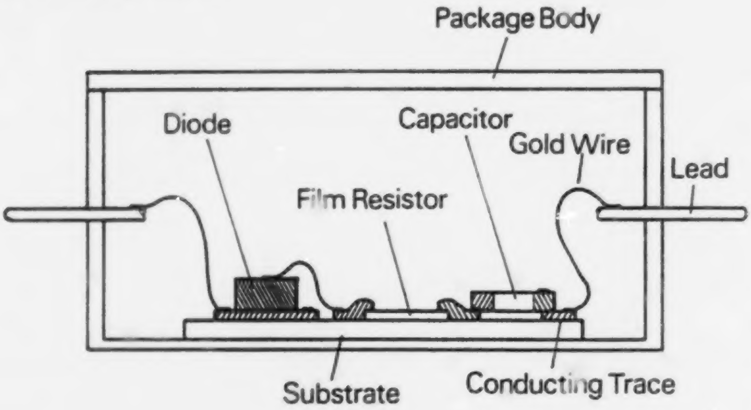
Monolithic I.C.

1. A thin-film I.C. is a circuit consisting of patterns of miscellaneous materials which have been laid down in very thin ribbons on a single substrate of insulating material, such as glass or ceramic.

2. Components such as resistors and interconnecting conductors are formed with extremely thin layers of metals and oxides on the insulating substrate.

3. A thick-film I.C. is a circuit in which resistors, capacitors and conductors are deposited on a substrate, usually through a silk-screen printing process.

D. Hybrid I.C.s are constructed with a combination of thin-film, thick-film and monolithic processes to form a complete circuit.


Package Body
Diode
Capacitor
Gold Wire
Lead
Film Resistor
Substrate
Conducting Trace

Hybrid I.C.

E. High-power or large components, such as coils and capacitors, are usually external components.

IV. Maximum operating range

A. The operating temperature is the range for which the operational amplifier (op amp) will operate within the manufacturer's specifications.

B. Supply voltage is the maximum positive and negative voltage that can be used to power the op amp.

C. The internal dissipation power is the maximum power that an op amp is capable of dissipating in a specified temperature range.

D. The input voltage is the maximum input voltage that can be simultaneously applied between both inputs and ground (often referred to as common-mode voltage).

E. The output short-circuit duration is the time that the output of the op amp can be short-circuited to ground or to either supply voltage.

F. Differential input voltage is the maximum voltage that can be applied across the positive and negative inputs.

V. Input and output parameters

A. Input resistance is resistance at either input to the op amp with the remaining input grounded.

B. Input offset voltage is the voltage that must be applied to one of the input terminals to give a zero output voltage.

C. Input bias current is the average of the currents flowing into both inputs; ideally, both bias currents are equal.

D. Input offset current is the difference of the two input bias currents when the output is zero.

E. The input voltage range is the range of the voltage common to both inputs and ground.

F. The output resistance is the resistance seen looking inward from the op amp output.

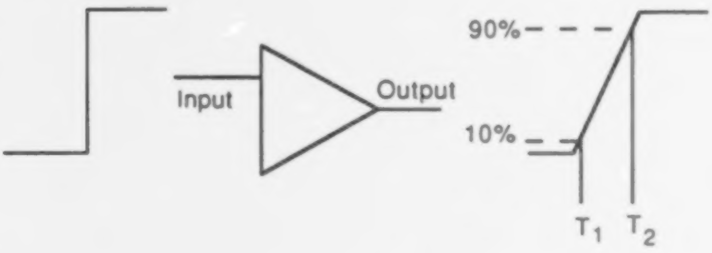
G. The output short-circuit current is the maximum output current that the op amp can deliver to a load.

H. Output voltage swing is the maximum peak output voltage that the op amp can supply without saturation or clipping.

VI. Dynamic parameters

A. Open-loop voltage gain is the ratio of the output to input voltage of the op amp without external feedback.

B. To determine the rise time of an amplifier, apply a fast rising pulse to the input and measure the time the output takes to rise from 10% to 90% of the maximim output (T_1 to T_2 in microseconds).



Rise time

C. Large-signal voltage gain is the ratio of the maximum voltage swing to the change in the input voltage required to drive the output from zero to a specified voltage.

D. Slew rate is the maximum rate of change of output voltage under large-signal conditions.

E. The common-mode rejection ratio, usually expressed in decibels, is a measure of the ability of the op amp to reject signals that are simultaneously present at both inputs.

F. The channel separation is the amount of "crosstalk" between op amps when multiple op amps are present in a single package.

VII. Basic operational characteristics of the op amp (TM 1.2, 1.3)

A. The op amp is a high gain amplifier consisting of several stages cascaded together.

B. The cascading of several different types of amplifier stages gives the op amp desirable characteristics.

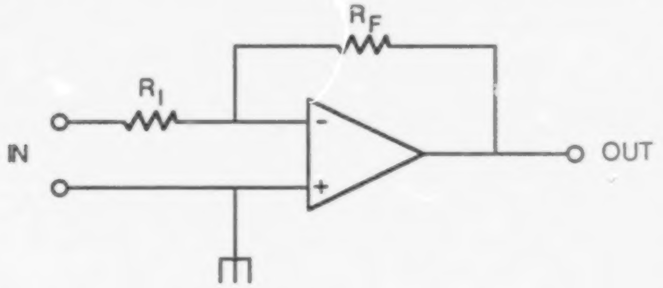
1. Very high gain
2. Very high input impedance
3. Very low output impedance
4. High common-mode rejection
5. Frequency response down to DC

C. The op amp can be operated in an open-loop mode. (Example: a comparator)

D. The op amp can be operated in a closed-loop mode. The two basic configurations are inverting and non-inverting.

VIII. Characteristics of the inverting amplifier (TM 1.4)

A. The inverting configuration is the most common of the op amp configurations.

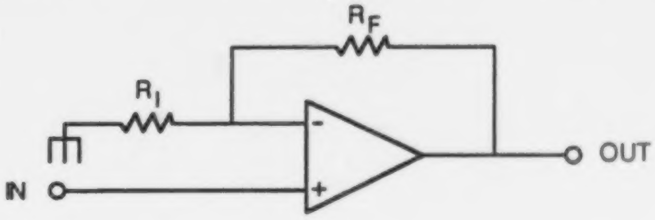


B. The output of the op amp in the inverting configuration is 180° out-of-phase with the input.

C. The voltage gain of the op amp stage is equal to the ratio of R_f to R_i. ($A = R_f / R_i$)

IX. Characteristics of the non-inverting amplifier (TM 1.5)

A. The non-inverting amplifier is used to provide an output that is in phase with the input.



R_f and R_I form a voltage divider network for feedback.

B. Stage gain can be obtained by using the following equation.

$$Av = 1 + \frac{R_f}{R_I}$$

C. Input impedance for a non-inverting amplifier is very high--greater than that of the op amp.

X. Relationship between gain, bandwidth and feedback (HO 1.1)

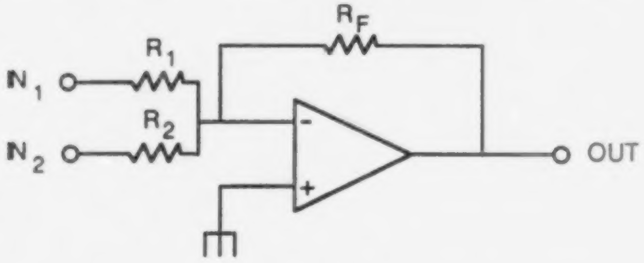
A. The gain of an op amp times the highest frequency which that configuration can amplify will equal the gain bandwidth product or unity gain specification for that op amp.

Formula: gain bandwidth = gain x frequency max.

B. Gain bandwidth is a fixed product. If gain is increased, the maximum frequency of the amplifier will decrease.

C. Characteristics of the summing and difference amplifiers (TM 1.6)

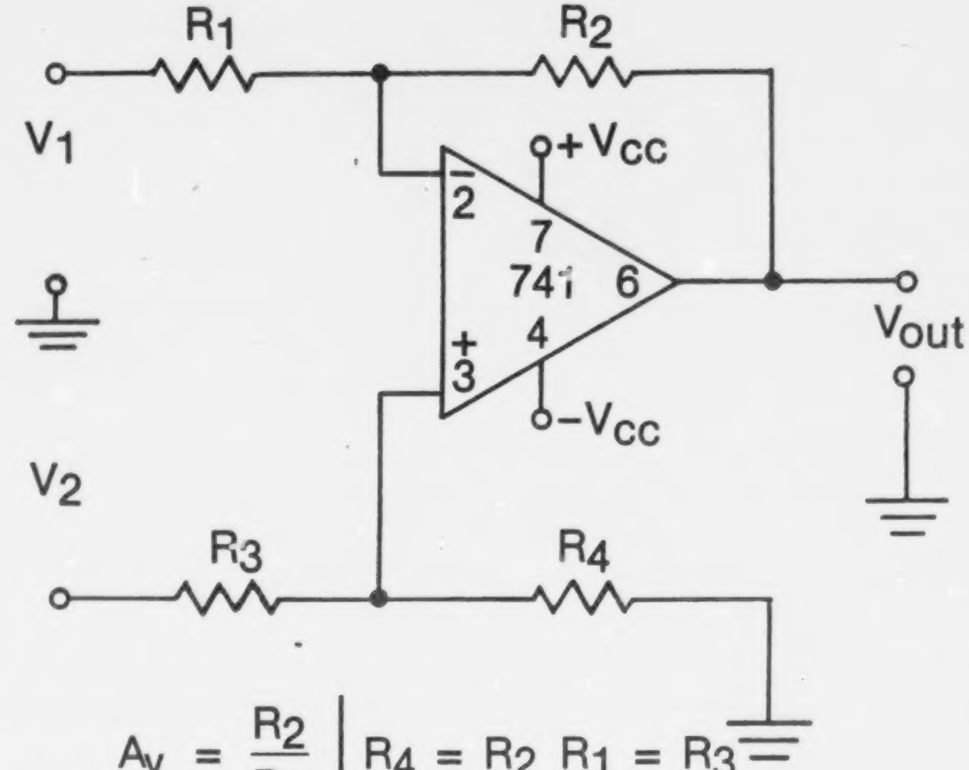
1. The summing amplifier has two or more inputs with one output.



NOTE: R_1 and R_2 could be adjustable, as in a multiple-microphone public address system.

2. The common point at which the input resistors are connected is known as the summing point.

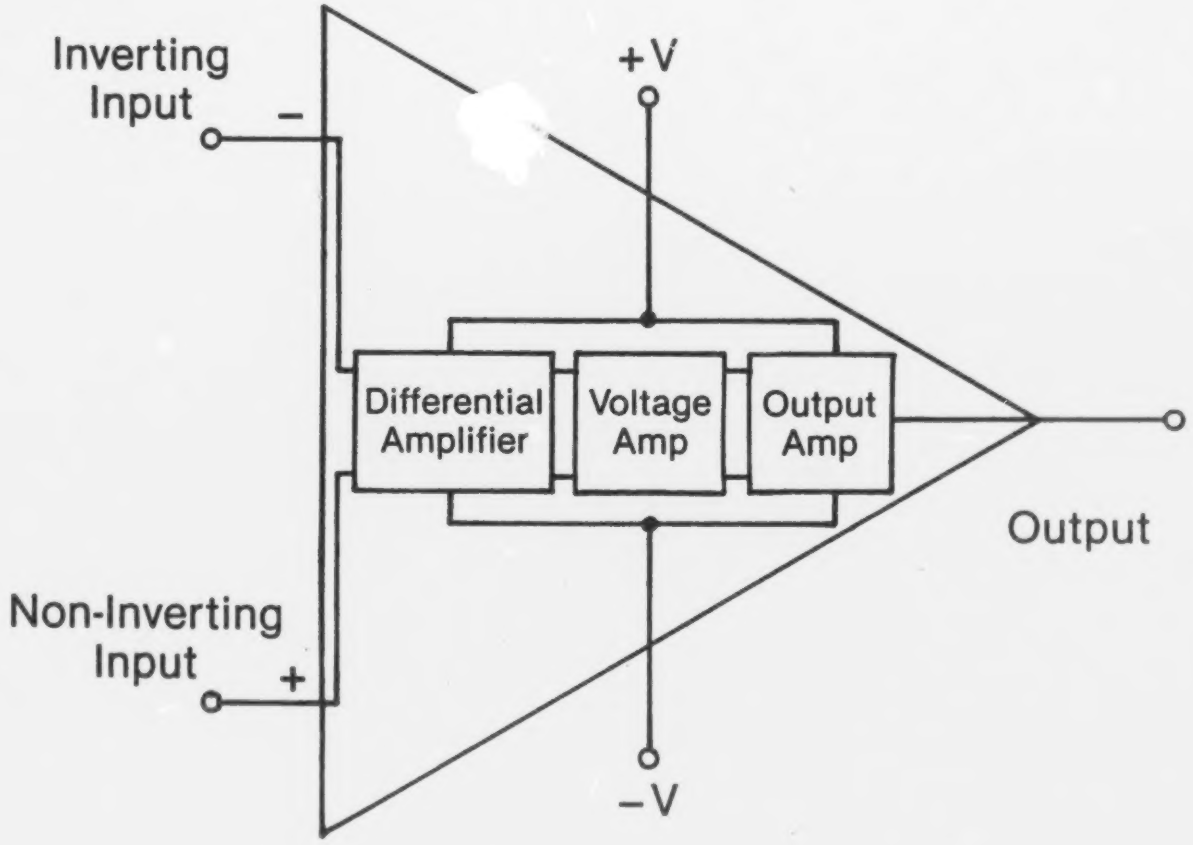
DIFFERENTIAL AMPLIFIER CIRCUIT

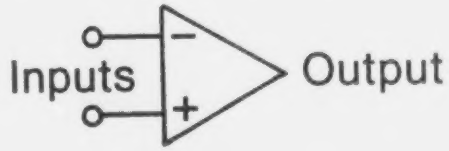

R_1
R_2
V_1
$+V_{CC}$
$-$
2
7
741
6
$+$
3
4
$-V_{CC}$
V_{out}
V_2
R_3
R_4

$$A_V = \frac{R_2}{R_1} \;\Big|\; R_4 = R_2 \quad R_1 = R_3$$

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

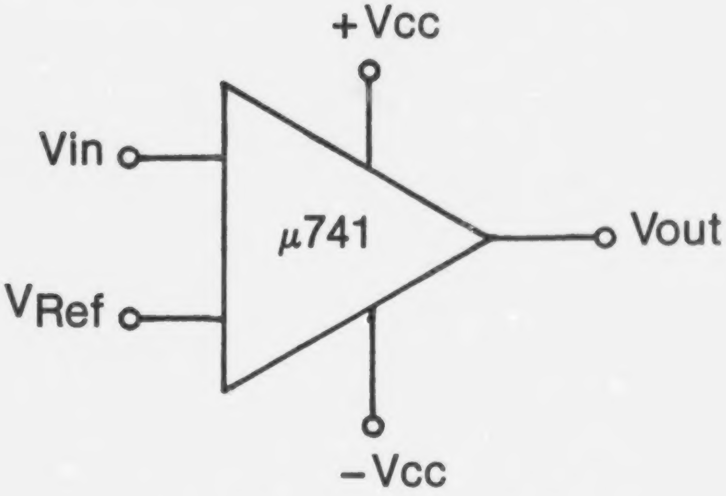
OPERATIONAL AMPLIFIER

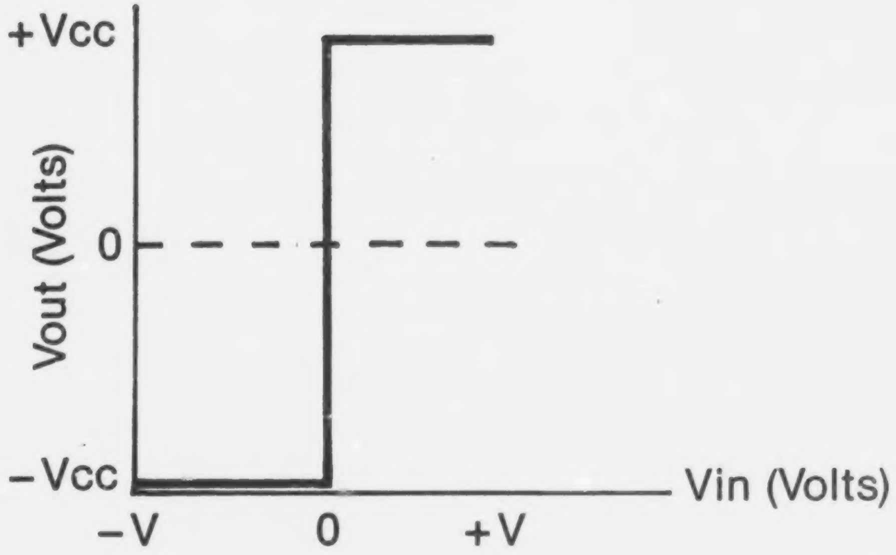

Inverting
Input
−
+V
Differential
Amplifier
Voltage
Amp
Output
Amp
Output
Non-Inverting
Input
+
−V


−
Inputs
+
Output

Schematic Symbol

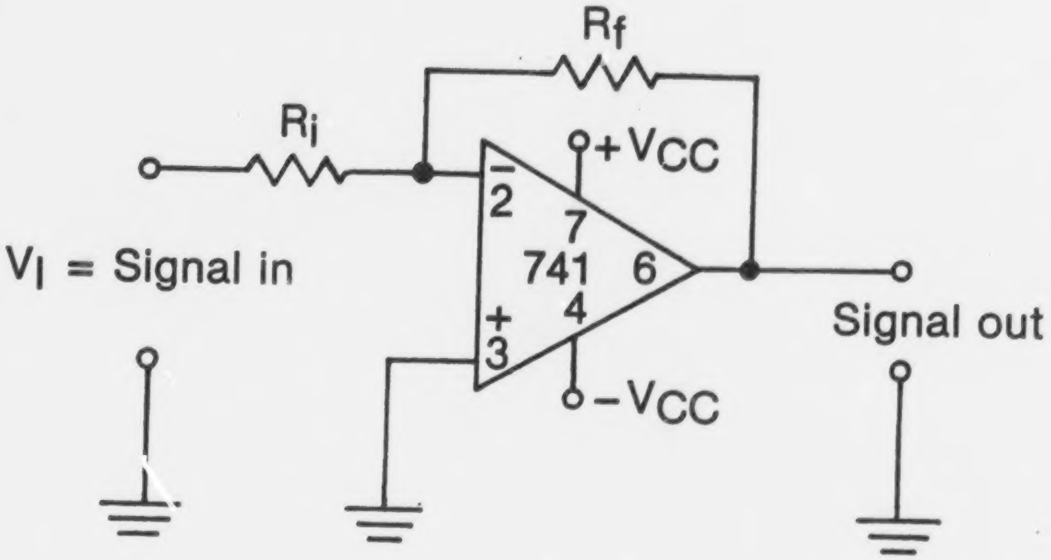
COMPARATOR


+Vcc
Vin
μ741
Vout
VRef
−Vcc



Ideal Comparator Output

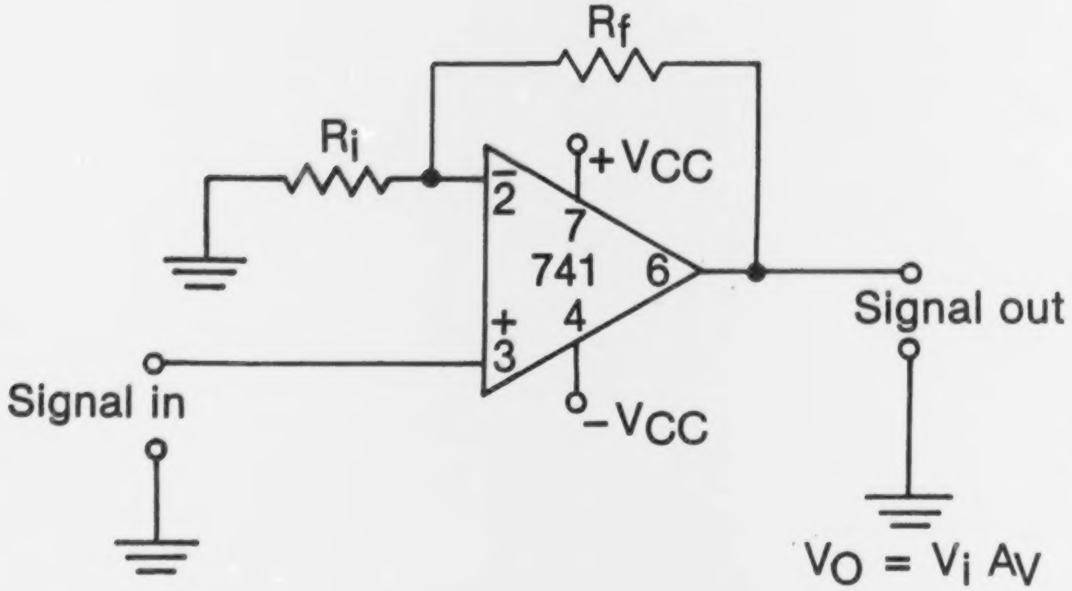
INVERTING AMPLIFIER


Rf
Ri
+VCC
−VCC
2
3
7
741
6
4
−
+
VI = Signal in
Signal out

$$A_V = \frac{-R_f}{R_i}$$

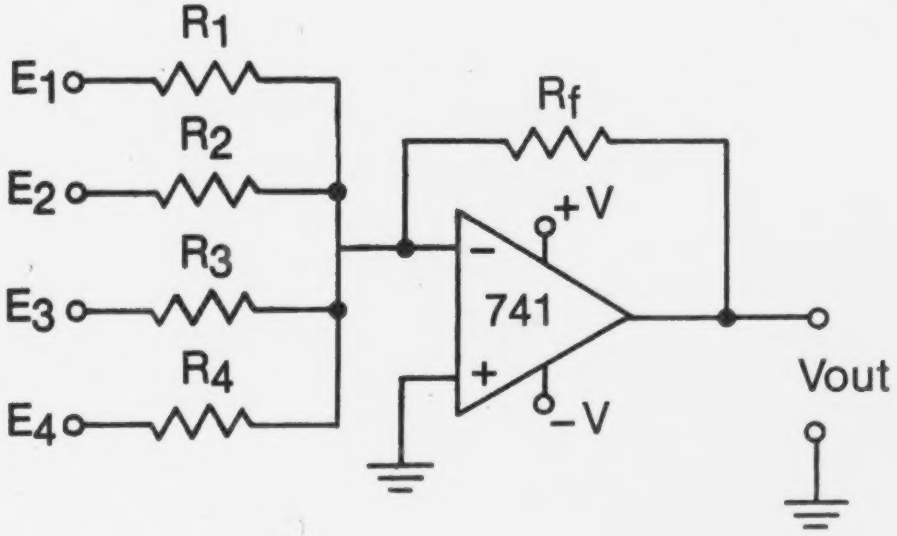
TM 1.5

NON-INVERTING AMPLIFIER


R_f
R_i
$+V_{CC}$
$-V_{CC}$
2
3
7
741
6
4
Signal in
Signal out
$V_O = V_i A_V$

$$A_v = \frac{R_i + R_f}{R_i} = 1 + \frac{R_f}{R_i}$$

SUMMING AMPLIFIER (MIXER)

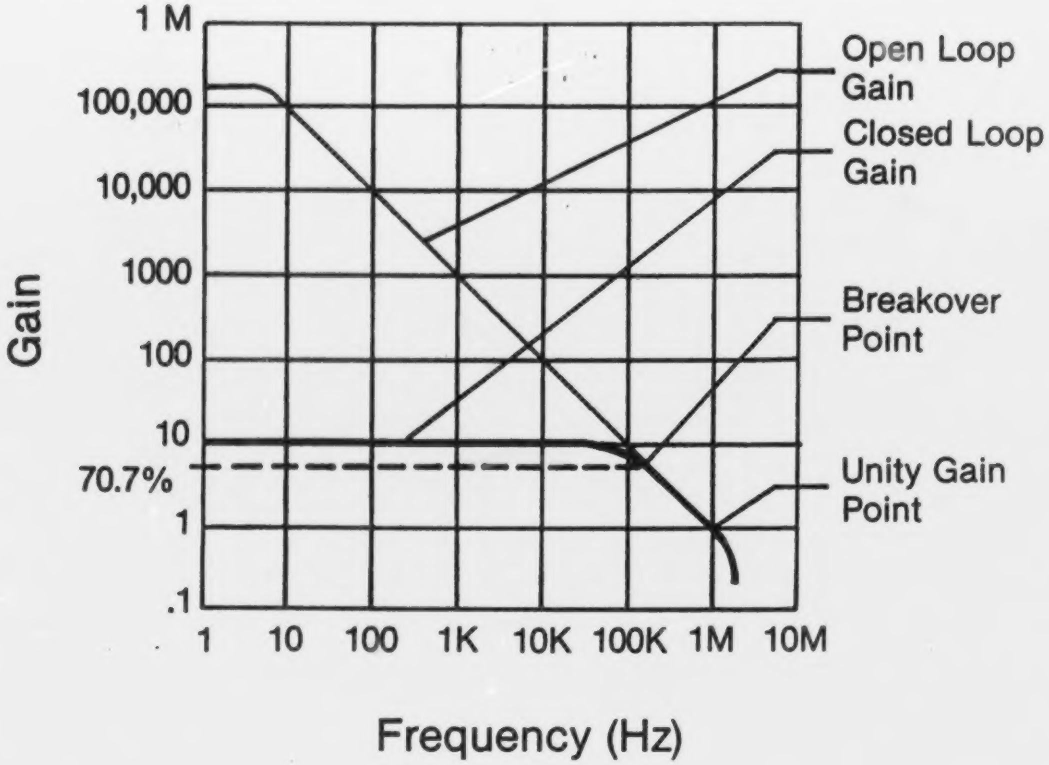

R_1
E_1
R_2
E_2
R_3
E_3
R_4
E_4
R_f
+V
−
741
+
−V
Vout

$R_1 = 8K$, $R_2 = 4K$, $R_3 = 2K$, $R_4 = 1K$, $R_f = 8K$

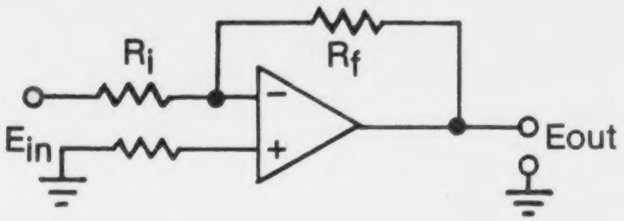
$$E_{out} = -\left(\frac{R_f}{R_1}E_1 + \frac{R_f}{R_2}E_2 + \frac{R_f}{R_3}E_3 + \frac{R_f}{R_4}E_4\right)$$

(for unequal resistors)

GAIN VS. BANDWIDTH



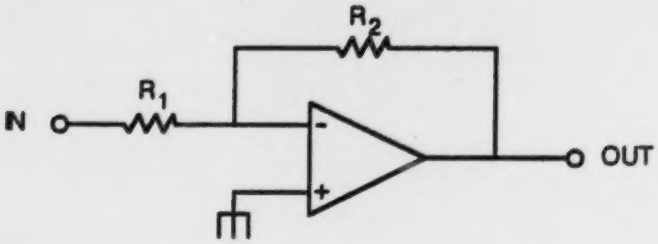
R_i	R_f	Gain	Bandwidth	R_{in}
10K	10K	1	1MHZ	10K
10K	1K	10	100KHZ	1K
100K	1K	100	10KHZ	1K
100K	100K	1000	1KHZ	100K



AS 1.1

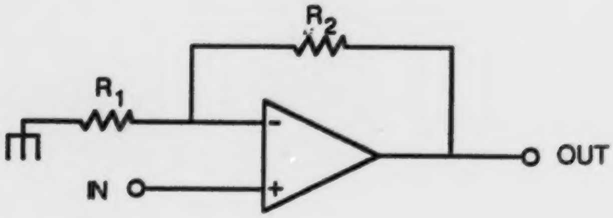
CALCULATE CLOSED-LOOP GAIN AND OUTPUT VOLTAGE

1. For the inverting amplifier shown below, calculate the closed-loop gain, given that R_1 = 10K and R_2 = 100K.



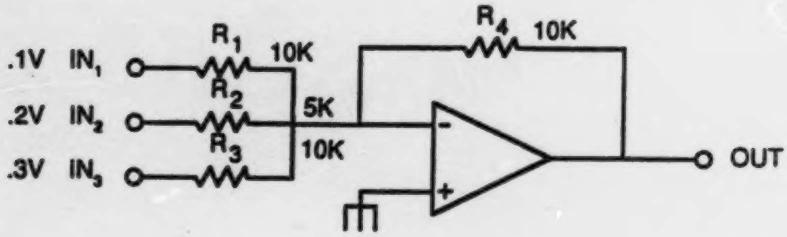
2. Calculate V_{out} for the above, given that V_{in} = +0.5 volts.

3. For the non-inverting amplifier schematic below, calculate the closed-loop gain, given that R_1 = 5K and R_2 = 10K.



4. Calculate V_{in} for #3, given that V_{out} = +10 volts.

5. For the schematic below, calculate V_{out}. (R_1 = 10K, R_2 = 5K, R_3 = 10K, R_4 = 10K)



.1V IN₁
.2V IN₂
.3V IN₃
R1 10K
R2 5K
R3 10K
R4 10K
-
+
OUT

6. Repeat #5, changing R_4 to 100K.

ANSWERS TO AS 1.1

1. AV = 11
2. 5.5V
3. AV = 2
4. 5V
5. $.2 + .6 + .6 = 1.2V_{out}$
6. $1.1 + 4.2 + 1.1 = 6.4V_{out}$

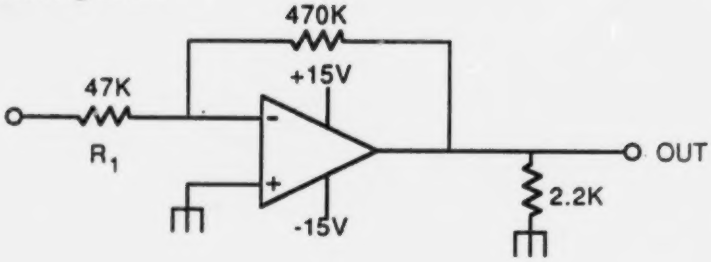
CONSTRUCT AND TEST AN INVERTING AMPLIFIER

Equipment:

Op amp, type LM741 or equivalent
Resistors: 470K, 1/4 watt
47K, 1/4 watt
2.2K, 1/4 watt
+15 volt DC power supply or dual tracking DC supply
Variable DC power supply (regulated)
Proto-board or equipment to connect an integrated circuit
Multimeter
Dual trace oscilloscope
Sine-wave generator

Procedure:

1. Connect the following circuit. __ __ __ __



NOTE: Review the data sheet for op amp pin connection.

2. Calculate the voltage gain. Calculate output voltage across the 2.2K load resistor. Record values in the following chart. __ __ __ __

3. Turn on the power supply (15V) to the op amp. __ __ __ __

   NOTE: Most op amps require a power supply that has a positive (+) and a negative (-) voltage with reference to a common point or ground.

4. Apply a DC 1V to input resistor R_1. Measure and record output and input voltages in the following chart. __ __ __ __

   NOTE: Be sure to observe the polarity of output voltage as compared to input voltage polarity.

DATA TABLE

AV calculated	V_{out} calculated	V_{in} measured	V_{out} measured	AV measured	% diff.

5. Using the measured values; calculate the voltage gain. (AV = V_{out} / V_{in}) Record in the above chart. — — — —

6. Determine the percent difference between the measured gain value (step 5) and the calculated gain value (step 2). Record in the chart above. Check calculations with your instructor. — — — —

7. Apply a sine wave (1.5V p-p) to the input in place of the 1V DC. — — — —

8. Observe input and output of the circuit with the dual trace oscilloscope. Repeat steps 2 through 8. — — — —

9. Return equipment and materials to their proper storage area. — — — —

Average of above evaluations* — — — —

*This average is the student's partial evaluation for competencies E3, E6 and E8.

JS 1.2

CONSTRUCT AND TEST A NON-INVERTING AMPLIFIER

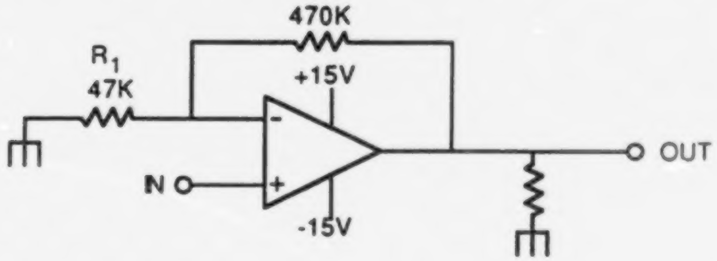
Equipment:

Op amp, type LM741 or equivalent
Resistors: 470K, 1/4 watt; 47K, 1/4 watt; 2.2K, 1/4 watt
+15V DC power supply or dual tracking DC supply
Variable DC power supply
Proto-board or equipment to connect an integrated circuit
Multimeter
Dual-trace oscilloscope
Sine-wave generator

Procedure: Evaluation 3 2 1 N

1. Connect the following circuit for a non-inverting DC amplifier. ___ ___ ___ ___

   WARNING: Do not turn on power at this time.



2. Calculate voltage gain. _________ Calculate output voltage. _______- ___ ___ ___ ___ ___

3. Turn on the +15V power supply. ___ ___ ___ ___

4. Apply a 1V DC to the non-inverting input (pin 3). Measure and record input and output voltages in the chart that follows. ___ ___ ___ ___

(+) V_{in}	V_{out}	Gain, based on measurements	Gain, based on feedback resistors
1 V_{DC}			
1.5 V_{DC}			
.1 V_{AC} at 1KHz			
.5 V_{AC} at 1KHz			
1.0 V_{AC} at 1KHz			
1.5 V_{AC} at 1KHz			
1.5 V_{AC} at 200KHz			

5. Based on voltage measurements, calculate and record op amp circuit gain. ___ ___ ___ ___

6. Based on feedback resistor values, calculate and record op amp circuit design gain. _ _ _ _

Average of above evaluations* _ _ _ _

*This average is the student's partial evaluation for competencies E3, E6 and E8.

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CONSTRUCT AND TEST A DIFFERENTIAL AMPLIFIER

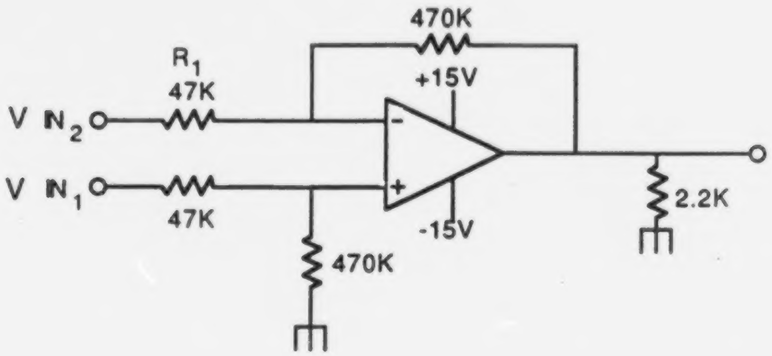
Equipment:

Op amp, type LM741 or equivalent
Resistors: 470K, 1/4 watt (2)
47K, 1/4 watt (2)
2.2K, 1/4 watt (1)
+15 volt power supply or dual tracking DC supply
Dual-polarity power supply (variable)
Proto-board or equipment to connect an integrated circuit

Procedure:

	Evaluation 3	 2	 1	 N
1. Connect the following circuit for a differential DC amplifier.	—	—	—	—

WARNING: Do not apply power at this time.



	3	2	1	N
2. Calculate output voltage (V_{out}).	—	—	—	—
3. Turn on the +15V power supply.	—	—	—	—
4. Apply 1.0V at V_1 and 1.5V at V_2.	—	—	—	—
5. Measure and record output and input voltages.	—	—	—	—
6. Compare the output voltage measured to the output voltage calculated. Adjust V_2 to 1V and measure output voltage.	—	—	—	—

V_{out} measured $V_1 = 1.0V$ $V_2 = 1.5V$	V_1 measured	V_2 measured	V_{out} calculated	V_{out} measured $V_1 = V_2 = 1.0V$	AC	AD

7. Using values from step 6, calculate the common mode gain by the following formula. — — — —

   $AC = V_{out} / V_{in}$

8. Calculate the difference mode gain with the following formula. Check calculations with your instructor. — — — —

   $AD = V_{out} / (V_{in1} - V_{in2})$

9. Return equipment and materials to their proper storage area. — — — —

Average of above evaluations* — — — —

*This average is the student's partial evaluation for competencies E3, E6 and E8.

CONSTRUCT AND TEST A DC SUMMING AMPLIFIER

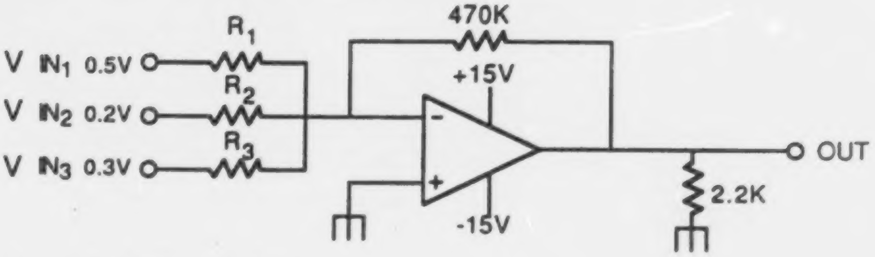
Equipment:

Op amp, type LM741 or equivalent
Resistors: 470K, 1/4 watt
47K, 1/4 watt (3)
2.2K, 1/4 watt
+15V power supply or dual tracking DC supply
Variable DC power supply
Proto-board or equipment to connect an integrated circuit
Multimeter

Procedure: Evaluation 3 2 1 N

1. Connect the following circuit for a DC summing inverting amplifier. — — — —

   WARNING: Do not turn on the power at this time.



R_1, R_2, R_3 each 47K

2. Calculate the output voltage. — — — —
3. Apply 0.5V to input V_1, 0.2V to input V_2 and 0.3V to input V_3. — — — —
4. Turn on the +15V power supply. — — — —
5. Measure and record output and input voltage. Observe polarity of the output voltage as compared to input voltage. — — — —

DATA TABLE

V_{out} calculated	V_{in} measured	V_{out} measured	% diff.	V_{out} 470KΩ calculated	V_{out} 4.7KΩ calculated

6. Compare output voltage measured to output voltage calculated. ____ ____ ____ ____

7. Compute output voltage if $R_1 = R_2 = R_3 = 470K\Omega$ resistance. ____ ____ ____ ____

8. Compute the output voltage if $R_1 = 4.7K\Omega$, $R_2 = 3.3K\Omega$ and $R_3 = 6.8K\Omega$. Check calculations with your instructor. ____ ____ ____ ____

9. Return equipment and materials to their proper storage area. ____ ____ ____ ____

Average of above evaluations* ____ ____ ____ ____

*This average is the student's partial evaluation for competencies E3, E6 and E8.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT X: LINEAR INTEGRATED CIRCUITS

UNIT TEST

Select the option which best answers the question or completes the statement.

____ 1. Which circuit amplifies the difference between two inputs?

a. Offset amplifier
b. Differential amplifier
c. Common mode amplifier
d. Open loop amplifier
e. Inverting amplifier

____ 2. Which gain configuration for any op amp will amplify the highest frequency?

a. Gain equals 1000
b. Gain equals 500
c. Gain equals 25
d. Gain equals 10
e. Gain equals 2

____ 3. Which of the following components would most likely be outside the I.C.?

a. Printed path
b. Small signal transistor
c. Capacitor
d. Resistor
e. Power transistor

____ 4. Which describes the differential amplifier?

a. 2 inputs, 1 output
b. 2 inputs, 2 outputs
c. 1 input, 1 output
d. 1 input, 2 outputs
e. 1 input, 3 outputs

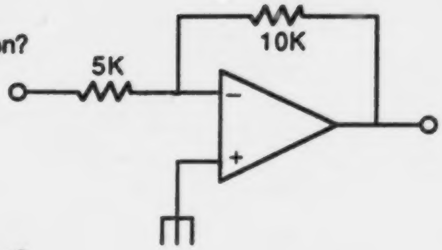
____ 5. What is measured to determine the output rise time of an op amp?

a. Time required for the output to rise from 10% to 90% of the peak value
b. Time required for the output to rise from 0% to 100%
c. Time required for the output to rise from 0% to 90%
d. Time required for output to rise from 10% to 100%
e. Time required for output to rise from 40% to 60% x 5

____ 6. An op amp has a unity gain frequency of 1.5 MHz and is configured for a voltage gain of 20. What is the highest frequency that it will amplify at the specified gain?

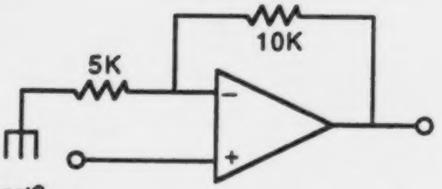
a. 1.5 MHz
b. 150 KHz
c. 75 KHz
d. 20 KHz
e. 10 KHz

___ 7. What is the gain of the following amplifier configuration?



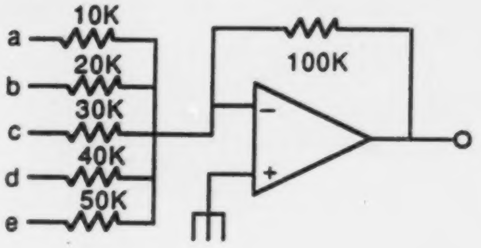
a. 2
b. 3
c. 20
d. 30
e. 50

___ 8. What is the gain of the following amplifier configuration?



a. 2
b. 3
c. 20
d. 30
e. 50

___ 9. In the following circuit, which input will be amplified least?



a. a
b. b
c. c
d. d
e. e

___ 10. What is the name of the circuit in question 9?

a. Multiple channel amplifier
b. Integrating amplifier
c. Differential amplifier
d. Summing amplifier
e. Comparator

Match the terms on the right with the corresponding definitions on the left.

____ 11. Application of an operational amplifier circuit that uses no external feedback

____ 12. Application of an operational amplifier circuit that uses external feedback

____ 13. Voltages that are simultaneously applied to both inputs of a differential amplifier

____ 14. Circuit that amplifies the difference between two inputs; the input stage of an op amp

____ 15. Classification of integrated circuits used for analog amplification purposes

____ 16. Complete electronic circuit that is fabricated on a single chip of silicon

____ 17. Component in a circuit which has gain or which directs the flow of current

____ 18. Coupling of voltage from the output of an amplifier back to its input

____ 19. Integrated circuit fabricated from a single chip of semi-conductor material, usually silicon

____ 20. Interference due to cross-coupling between adjacent circuits or to intermodulation of two or more carrier channels

____ 21. Solid-state I.C. amplifier with very high gain and differential inputs; uses external feedback to control its gain

a. Active device

b. Analog

c. Closed-loop operation

d. Common-mode signal

e. Comparator

ab. Crosstalk

ac. DC offset voltage

ad. Differential amplifier

ae. Feedback

bc. Gain bandwidth product

bd. Integrated circuit

be. Linear I.C.

cd. Monolithic I.C.

ce. Open-loop operation

de. Op amp

Select the option which answers the question or completes the statement.

____ 22. Which describes the maximum voltage that can be applied across an op amp's positive and negative inputs?

a. Supply voltage
b. Internal dissipation power
c. Differential input voltage
d. Input voltage
e. Output short-circuit duration

____ 23. Which describes the voltage that must be applied to one of the input terminals to give a 0V output?

a. Input resistance
b. Input offset voltage
c. Input bias current
d. Input offset current
e. Input voltage range

___ 24. Which is not a desirable op amp characteristic?

a. Very high gain
b. Very high input impedance
c. Very low output impedance
d. Frequency response down to DC
e. Low common-mode rejection

___ 25. Which formula is used to determine the voltage gain of an inverting amp?

a. $Av = 1 + \frac{R_f}{R_i}$
b. $A = R_f / R_i$
c. $V_{in} = A(V_{in1} - V_{in2})$
d. $B = R_i / R_f$
e. $V_{out} = A(V_{in1} - V_{in}2)$

___ 26. Which formula is used to determine stage gain of the non-inverting amplifier?

a. $Av = 1 + \frac{R_f}{R_i}$
b. $A = R_f / R_i$
c. $V_{in} = A(V_{in1} - V_{in2})$
d. $B = R_i / R_f$
e. $V_{out} = A(V_{in1} - V_{in2})$

ANSWERS TO UNIT TEST (E3)

1. b
2. d
3. c
4. b
5. a
6. c
7. a
8. b
9. e
10. d
11. ce
12. c
13. d
14. ad
15. be
16. bd
17. a
18. ae
19. cd
20. ab
21. de
22. c
23. b
24. e
25. b
26. a

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XI: THYRISTORS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to describe the operation of SCRs and TRIACs. This knowledge will be evidenced by achieving the specified score on the job sheets and unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Explain thyristor terminology.

1.2 Identify the anode, cathode and gate of the SCR.

1.3 List the requirements for turning an SCR on and off.

1.4 Describe how the thermal problems encountered in SCR circuits can be alleviated. (competency D10)

1.5 Construct SCR circuit and verify operation. (competencies D10 and D15, JS 1.1)

2.1 Identify characteristics of common TRIAC circuits.

2.2 Construct TRIAC circuits and verify operation. (competencies D9, D11 and D15, JS 2.1)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XI: THYRISTORS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the Instructor

D. Lesson plan

1. Lesson 1: SCRs
    - a. Information outline
    - b. Assignment sheet
        - AS 1.1: SCR operation
    - c. Answers to assignment sheet
    - d. Job sheet
        - JS 1.1: Construct SCR circuit and verify operation
2. Lesson 2: TRIACs
    - a. Information outline
    - b. Assignment sheet
        - AS 2.1: TRIAC operation
    - c. Answers to assignment sheet
    - d. Job sheet
        - JS 2.1: Construct TRIAC circuits and verify operation

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Humphries, James T., and Leslie P. Sheets. Industrial Electronics. 2nd ed. Boston: Breton Publishers, 1986.

2. Maloney, Timothy J. Industrial Solid State Electronics. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, 1986.

3. Malvino, Albert Paul. Electronic Principles. New York: McGraw-Hill Book Co., 1988.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Discuss industrial uses of SCRs and TRIACs in detail.
2. Explain the operation of individual devices.
3. Discuss common circuits that SCRs and TRIACs are found in.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XI: THYRISTORS

LESSON 1: SCRs

NOTE: AC control systems that handle large amounts of current often use the SCR or TRIAC. One example of such a device is a light dimmer switch. Energy-efficient furnaces and air conditioners often use TRIACs in the blower motor's variable speed control.

I. Terms and definitions

A. Thyristor–general name given to the family of electronic switching devices

Examples: SCR, TRIAC, DIAC, UJT

B. SCR (silicon-controlled rectifier)--four-layer semiconductor device which blocks the flow of current in either direction until "gated." Once gated, it allows current flow in one direction; this flow continues until an external force stops it.

C. Gate turn-on voltage (V_{GT})--gate-to-cathode voltage required to turn on the SCR

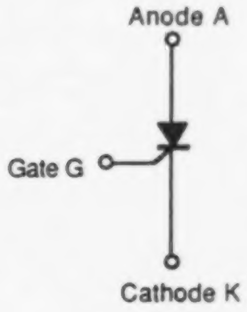
D. Gate turn-on current (I_{GT})--gate-to-cathode current needed to turn on the SCR

E. Forward voltage (V_F)--voltage from anode to cathode when the device is forward biased

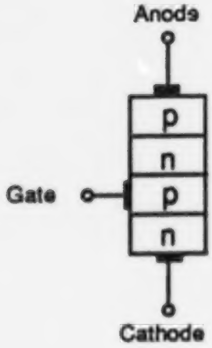
F. Breakover voltage (V_{BO})--voltage from anode to cathode that will cause current to flow, regardless of gate current

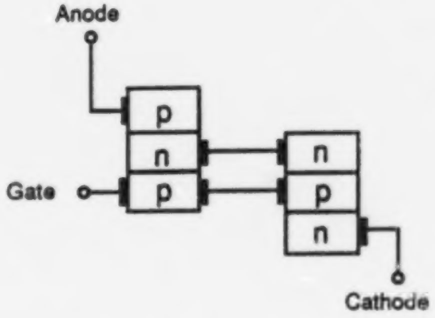
II. SCR description

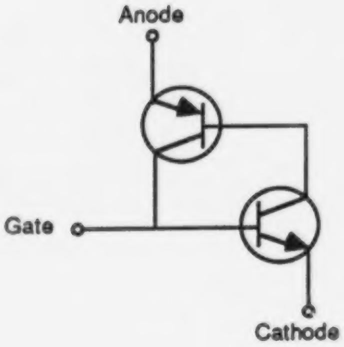
A. Schematic symbol



B. Structure







III. SCR operation

A. Turning on the SCR

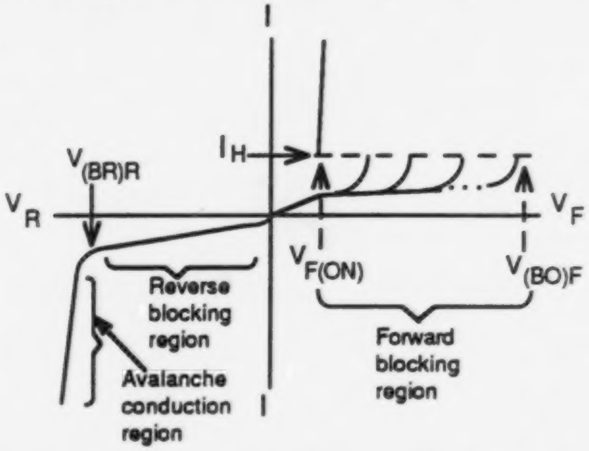
1. Voltage and current requirements for the most common method of turn-on (gate voltage control)

   a. V_{GT} usually equals 1-3 volts.

   b. I_{GT} ranges from 1-150mA.

2. SCR current-voltage characteristic curve

   a. The following illustrated SCR has no gate current because the gate is grounded.



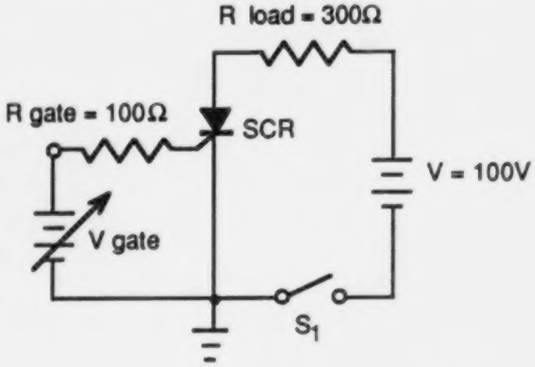
   b. The forward blocking region is displayed when the SCR is forward-biased (positive voltage on the anode with respect to the cathode). Very little current flows.

   c. When V_F reaches $V(_{BO)F}$, the device breaks into conduction, just as if a gate current was drawn.

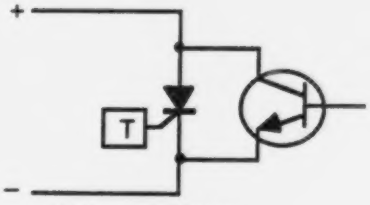
   d. When the SCR is reverse biased, little current flows in the reverse blocking region. When the reverse breakdown voltage $V_{(BR)R}$ is reached, the device quickly goes into avalanche conduction, which usually destroys the device.

B. Turning off the SCR is the only way is to reduce anode current below the holding current value.

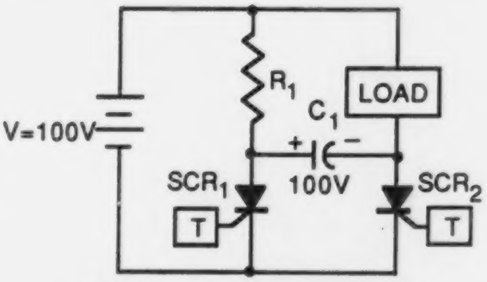
1. In DC circuits this can be accomplished with the reset switch.



2. Commutation capacitor--When SCR$_2$ is turned on by a gate pulse, anode current flows through the load and also charges C through R. (SCR$_1$ is off.) Because SCR$_2$ drops so little voltage in its on state, capacitor C charges to about 100V. SCR$_2$ can be turned off by triggering SCR$_1$ into conduction. When SCR$_1$ turns on, it reverse-biases SCR$_2$ by placing -100V across it from anode to cathode.



With a transistor



With a commutation capacitor

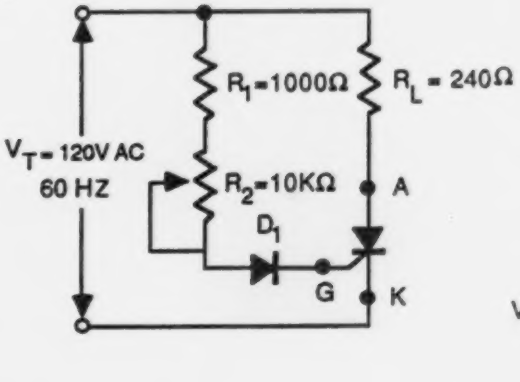
3. Turn SCR off by turning on a transistor--When Q is forward-biased to saturation, it conducts current around the SCR. In a properly designed circuit, the anode current falls below the holding current and the SCR turns off.

4. AC circuits

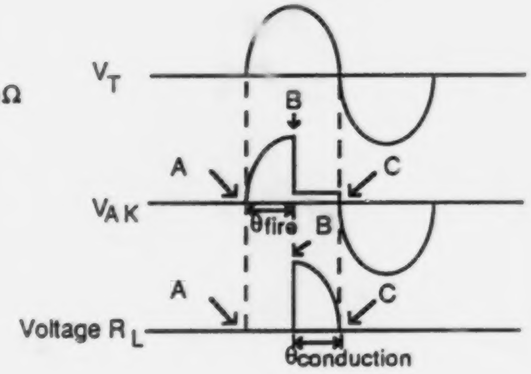
   a. The SCR is automatically shut off during each cycle when the AC voltage across the SCR approaches zero.

   b. As supply goes positive in the following circuit, an increasing amount of gate current is drawn. The SCR blocks (between points A and B) until V_T rises to V_{GT} (point B).

Circuit



Waveforms

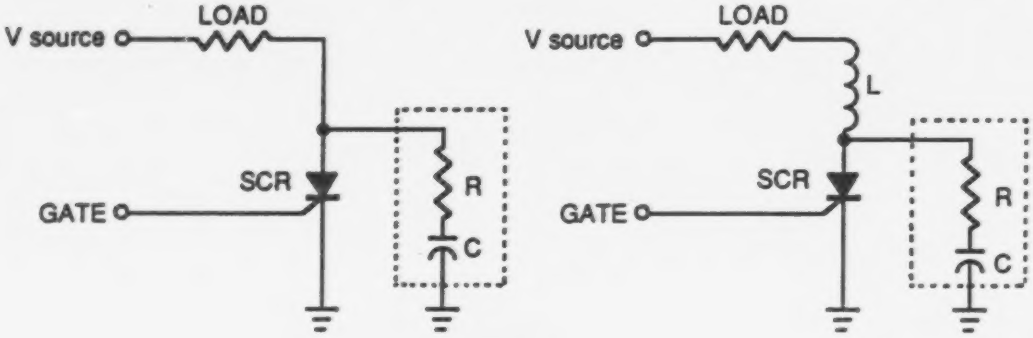


c. At point B the SCR quickly turns on and load current flows. The current through the SCR rapidly rises to a peak and decreases as the AC supply voltage decreases toward zero. Finally, at point C the anode current falls below the holding current value and the SCR turns off.

C. Critical rate of rise is expressed in volts per microsecond.

1. Rate effect turn-on method–When a quickly rising voltage is applied between the anode and the gate, charge current flows because of the capacitance in PN junctions. If high enough, it can trigger the SCR into conduction. Maximum line frequency is limited.

2. Snubber circuit–delays the rate of the anode voltage rise



Snubber circuit

3. Critical rate of current rise–expressed in amperes per microseconds. (Example: For 2N1595 it is 25 A/µs.) If exceeded, hot spots develop within the device, which may destroy it. This can be prevented by putting an inductor in series with the anode (shown above).

IV. Thermal considerations

A. Most SCRs handle large amounts of power. The case is frequently too small to dissipate the heat.

B. Heat sinks are devices that, when attached to the semiconductor, will aid in getting rid of the heat generated.

C. Thermal resistance measures how well the device conducts heat away from the junction. It is defined as the quotient of the temperature drop between two points and the power passing between them.

1. Junction-to-case thermal resistance

2. Case-to-sink thermal resistance–To reduce the thermal resistance between the case and sink (allowing better conduction of heat), four factors must be kept in mind.

a. Keep surfaces as smooth as possible.

b. Keep surface areas between the two as high as possible.

c. Use thermal joint compound (such as silicon grease) to keep the thermal conductivity of the medium between the surfaces as great as possible.

    d. Where bolts, screws or studs are used for mounting the sink, apply tightening torques according to the manufacturer's recommendations.

3. Sink-to-ambient thermal resistance is probably the most important thermal resistance in keeping the semiconductor junction cool.

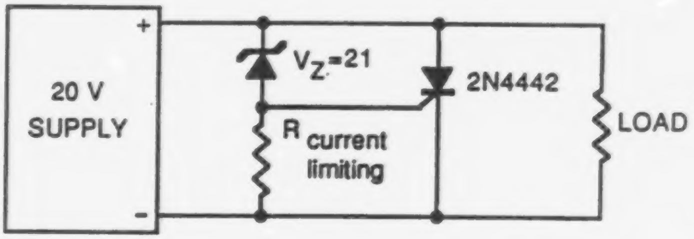
D. Installing, mounting and cooling considerations--To obtain maximum efficiency and greater reliability in the use of power semiconductors, heat must be removed as quickly as possible. There are three obstacles to overcome.

1. Interface and material between the semiconductor device mounting surface and semiconductor element

2. Interface between the device mounting surface and the heat sink

3. Transfer of heat through the heat sink to the ambient, which might be natural convection air, forced air, oil or water

E. Application--SCR crowbar circuit (over-voltage protection)



SCR crowbar

1. Soft turn-on circuit--As long as supply voltage is 20V, the zener is open, SCR gate voltage is zero and 20V appears across the load resistor

    a. If supply voltage tries to rise above 21V, the zener breaks down and a voltage appears at the gate of the SCR.

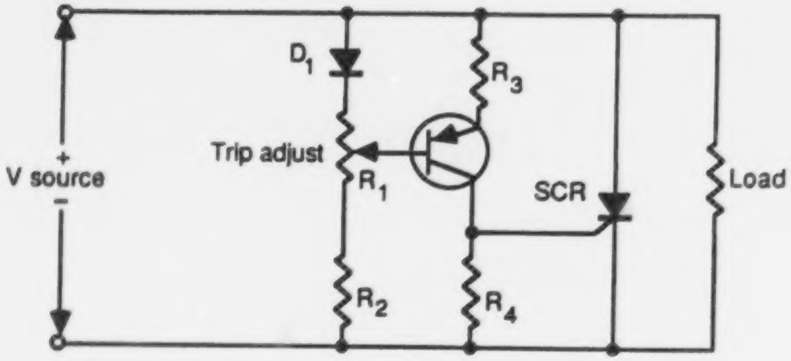
    b. When it exceeds about .7V, the SCR latches and shorts out the load voltage (similar to throwing a crowbar across the load terminals).

    c. SCR turn-on is very fast, and load is quickly protected from over-voltage.

2. Transistor crowbar--more practical. The transistor provides voltage gain, which produces a much sharper turn-on.

    a. An ordinary diode is included for temperature compensation of the transistor's base-emitter diode.

    b. The trip adjust allows the trip point of the circuit to be set at about 10-15% above the normal voltage.


D$_1$
R$_3$
Trip adjust
+
V source
−
R$_1$
SCR
Load
R$_2$
R$_4$

SCR OPERATION

Select the option which completes the statement.

1. An SCR is a more versatile device than the diode silicon rectifier because anode current can be controlled by the level of (gate / alternating) current.

2. The forward breakover voltage of a particular SCR is 150V (anode to cathode), where there is 1.5mA of gate current. If the gate current is increased to 2.5mA, the forward breakover voltage will become (higher / lower) than 150V.

3. An SCR can be used as an alternating-current (amplifier / rectifier).

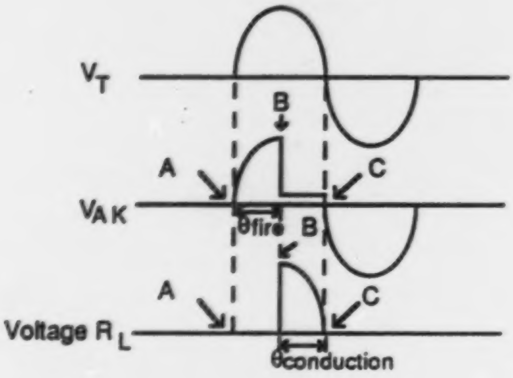
4. Once an SCR fires, it remains on until the anode forward voltage has been (added / removed) or until the anode forward-voltage level is below that required to maintain the holding current.

5. When the anode source of an SCR is alternating voltage, the rectifier turns (on / off) during the negative alternation.

6. The holding current is the (gate / anode) current below which the SCR turns off.

7. True or false: The current waveform in the figure below shows that load current remains constant during the time that the SCR is on.

Waveforms



8. True or false: The gate current source of an SCR can be either AC or DC.

9. True or false: The forward-bias, anode to cathode, voltage of an SCR is DC. The level of gate current is adjusted to fire the SCR. Once it has fired, the SCR can be turned off by reducing the gate current.

ANSWERS TO AS 1.1

1. Gate
2. Lower
3. Rectifier
4. Removed
5. Off
6. Anode
7. False
8. True
9. False

JS 1.1

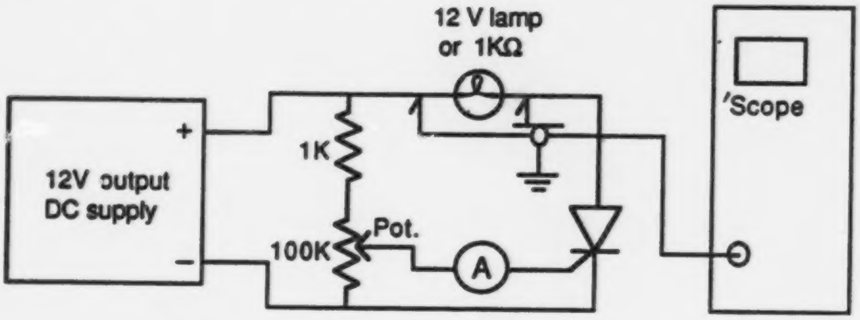
CONSTRUCT SCR CIRCUIT
AND VERIFY OPERATION

Equipment:

SCR (any general-purpose SCR, such as 2N5064 or 2N4444)
Potentiometer, 100KΩ, 1/2 watt
Resistor, 1KΩ, 1/2 watt
12V lamp
$12V_{DC}$ power supply
Transformer, general purpose $115\text{-}120V_{AC}$
Oscilloscope
Multimeter

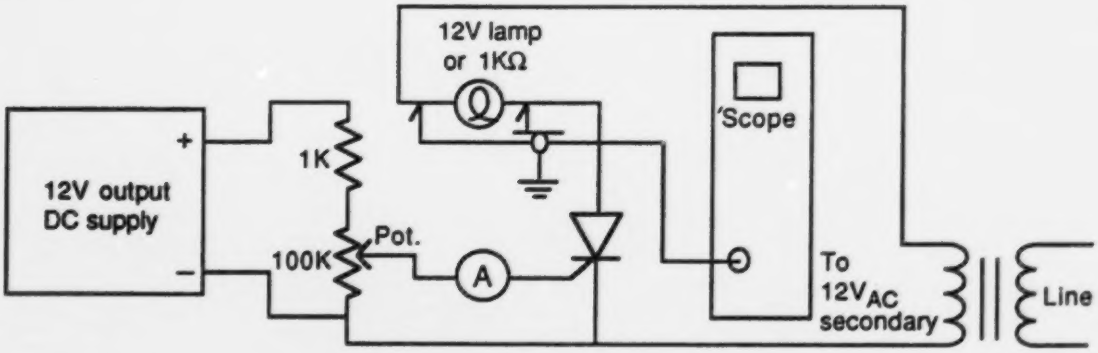
	Evaluation			
Procedure:	3	2	1	N
1. Connect the following circuit.	___	___	___	___

NOTE: Make certain the potentiometer wiper is at the bottom point when connecting circuits in this job sheet.



2. Adjust the potentiometer wiper upward until the lamp comes on or a sharp DC voltage rise is seen on the oscilloscope. Measure and record the SCR gate current. ______mA What is the voltage reading across the lamp or resistor? ______V_{DC}	___	___	___	___
3. Disconnect the SCR gate lead; the SCR should continue to conduct. The lamp should remain on. Did it? ______	___	___	___	___
4. Disconnect the DC supply positive lead to the SCR, then reconnect it. The SCR conduction should now remain off. Did it? ______	___	___	___	___

5. Construct the following circuit. _ _ _ _


12V lamp or 1KΩ
'Scope
+
12V output DC supply
−
1K
Pot.
100K
A
To 12V$_{AC}$ secondary
Line

NOTE: A shielded cable is shown by the symbol

6. Adjust the wiper of the potentiometer upward to the point that the SCR fires. The lamp will come on and there will be an observable signal on the oscilloscope. Sketch the current (voltage waveform) across the lamp in the space below. _ _ _ _

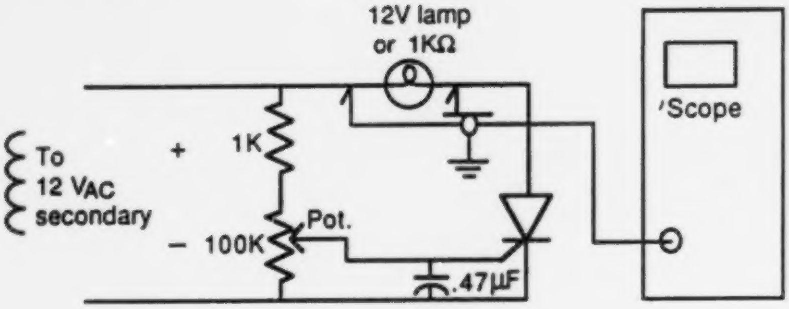
7. Decrease (lower) the potentiometer wiper until the SCR is turned off and then on again several times. _ _ _ _

8. Describe how the SCR responded to a DC supply compared to an AC supply. _ _ _ _

9. Why would the SCR be unsuitable as a control device in a DC system? _ _ _ _

10. After the gate is turned off in an AC system, when does the SCR turn off? _ _ _ _

11. Connect the following circuit. — — — —



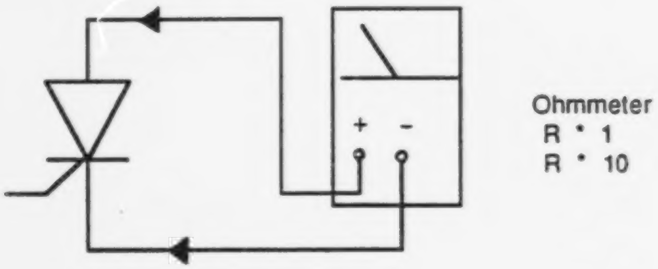
12. Slowly adjust the potentiometer upward until the lamp just begins to glow or the SCR just fires. Sketch the waveform in the space below. — — — —

13. Gradually increase the SCR firing current until a maximum value is reached. Sketch the waveform below. — — — —

14. Vary the potentiometer from minimum to maximum while observing the waveform across the lamp or resistor. What happens to the current waveform through the SCR as seen across the lamp? — — — —

15. Explain how the AC on the gate allowed a dimmer circuit, while the DC on the gate was simply an on-off controller. (Look at the AC signal on the gate as you vary SCR conduction.) — — — —

16. Connect the following circuit. — — — —



NOTE: The positive lead is the positive voltage output lead and not necessarily the red ohmmeter lead.

17. **The ohmmeter should indicate infinity. Did it? ______ Momentarily touch the anode to the gate. The SCR should conduct and the resistance should drop to a low value. Did it? ______** ___ ___ ___ ___

18. **Disconnect and reconnect the ohmmeter to the SCR anode. The resistance should be infinity again. Was it? ______** ___ ___ ___ ___

19. **As directed by instructor, prepare for next job sheet or clean up area and return tools and materials.** ___ ___ ___ ___

Average of above evaluations* ___ ___ ___ ___

***This average is the student's final evaluation for competency D10 and partial evaluation for D15.**

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

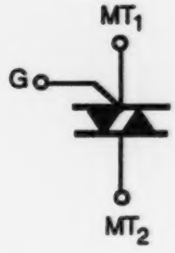
UNIT XI: THYRISTORS

LESSON 2: TRIACs

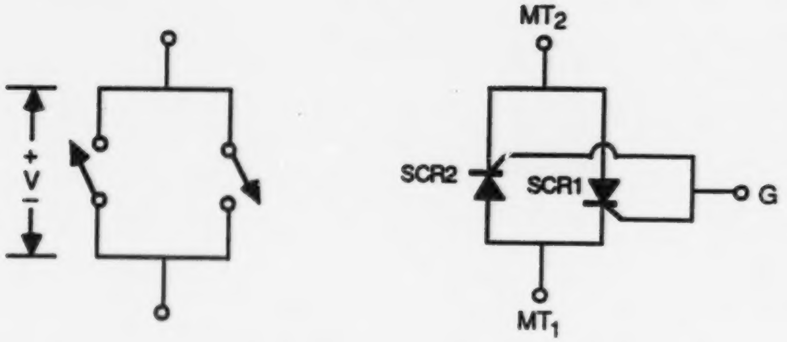
I. TRIAC description, operation and use

A. General description

1. Schematic symbol



2. Structure



TRIAC electrical equivalent

3. A TRIAC is a five-layer semiconductor device which is the equivalent of two SCRs connected together in parallel (but pointing in opposite directions) and having the gate leads connected together.

   a. Each half independently operates as an SCR.

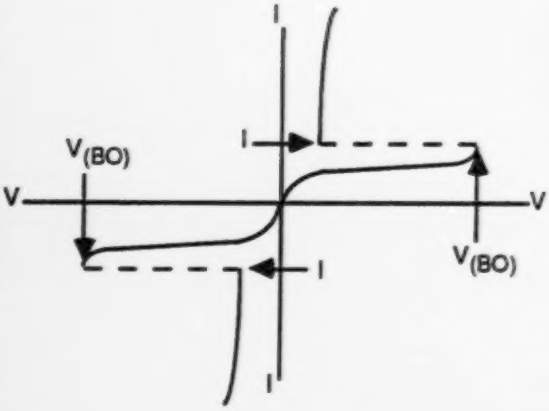
   b. Current can pass in both directions, flowing through one SCR in one direction and through the other SCR in the opposite direction.

B. Operation–Gate leads of both SCRs are connected together. SCR_1 fires and current flows from MT_1 to MT_2. When SCR_2 fires, current flow is in the opposite direction. A current-voltage graph shows the device's bi-directional nature.

C. Use–ideal for AC control circuits. Since the SCR is a unidirectional device, it has no control over half of each input cycle. The TRIAC can control current flow through a load driving both halves of the input cycle.

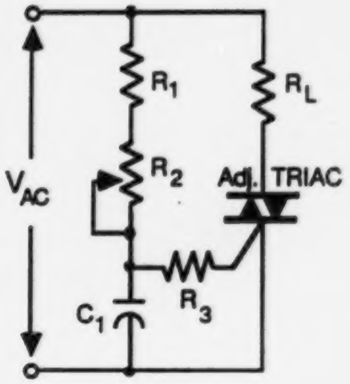
1. The following circuit is an example of a simple TRIAC-controlled AC circuit. The capacitor charges in either direction until $V_{(BO)}$ is reached. The TRIAC then fires and stays on throughout the remainder of that half-cycle. When AC input voltage nears zero, the TRIAC turns off.

2. Main terminal current falls below holding current (amount required to keep a TRIAC turned on). Phase control is achieved by varying the resistance of R_2.

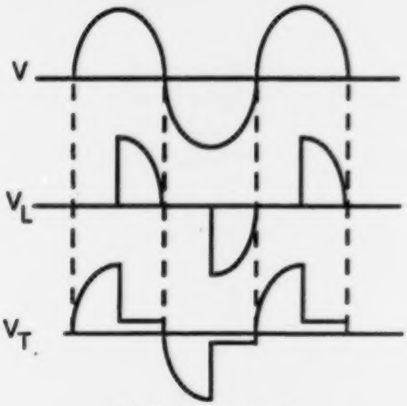


Voltage-current curves

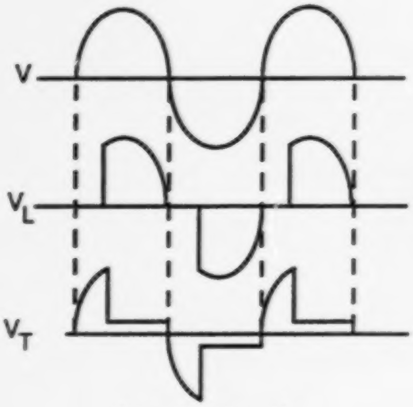
3. The power loss in a TRIAC is low compared to a rheostat because the TRIAC is only on when power is required, whereas the rheostat constantly consumes power.



Circuit



High firing angle



Low firing angle

4. A DIAC semiconductor can be used to make the TRIAC fire more consistently.

AS 2.1

TRIAC OPERATION

1. Draw the schematic symbol of a TRIAC and identify all three terminals.

2. What polarity of main terminal voltage is called the **positive** polarity?

   What is the **negative** polarity?

3. Does the firing delay angle of a TRIAC during the positive half cycle necessarily equal the firing delay angle during the negative half cycle? __________ Why?

4. Define V_{GT}.

   What range of values does it have for medium-sized TRIACs?

5. Define I_{GT}.

   What range of values does it have for medium-sized TRIACs?

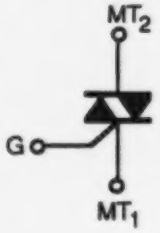
6. Define I_{HO}.

   What range of values does it have for medium-sized TRIACs?

7. Define V_{DROM}.

   All else being equal, which would cost more--a TRIAC with high V_{DROM} or a TRIAC with low V_{DROM}?

ANSWERS FOR AS 2.1

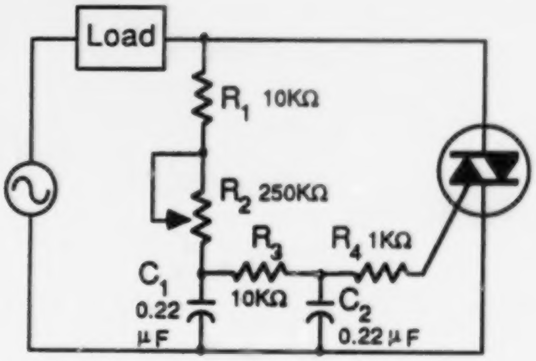


1. (see illustration→)
2. When MT_2 is more positive than MT_1
   When MT_1 is more positive than MT_2
3. No, due to wide variations in electrical characteristics
4. V_{GT} is the gate voltage necessary to trigger a TRIAC. Its normal range is about 0.6-2.0V.
5. I_{GT} is the gate current necessary to trigger a TRIAC. Its normal range is about 0.1-20 mA.
6. I_{HO} (holding current) is the main terminal current required to keep to the TRIAC turned on. Its normal rating is less than 100 mA.
7. V_{DROM} is the highest main terminal peak voltage the TRIAC can block in either direction. A TRIAC with a high V_{DROM}
8. V_{TM} is the voltage between the main terminals when the TRIAC is on. A low V_{TM} is more desirable since the TRIAC should act like a switch. The lower the voltage, the less power that is consumed by the device.
9. A TRIAC has a lower voltage drop and therefore less power loss.

CONSTRUCT TRIAC CIRCUITS AND VERIFY OPERATION

Equipment:

Power supply: 115V_{AC} isolated supply
Oscilloscope
Multimeter
250KΩ potentiometer
100W light bulb (or 100Ω, 100W resistor)
Breadboard
Hook-up wire
Resistors: 220K, 33K, 10K, 4.7K, 1KΩ, 1/2 watt
Capacitors: two 0.22μF, 0.1μF, 0.02μF
Semiconductors: TRIAC 2302B, DIAC TI43A



Procedure:

Evaluation
3 2 1 N

1. Construct the circuit using the following component sizes and ratings: R_{LD} = 100Ω, 100W resistor or 100W light bulb; TRIAC T2302B (RCA) or any TRIAC with a V_{DROM} of at least 200V, and $I_{T(RMS)}$ of at least 3A and with similar gate characteristics. If the gate characteristics (V_{GT} and I_{GT}) are not similar to the T2302B, triggering circuit components must be changed.
   Operate the potentiometer through the full range of adjustment. Measure the maximum delay angle for the TRIAC firing. — — — —

2. What is the adjustment range of the firing delay angle? — — — —

   Are the firing delays equal for both half cycles?

   Using the same time reference, make a sketch of the waveforms of V_{LD} and $V_{MT2\text{-}MT1}$.

   Measure I_{GT} (the current necessary to trigger the TRIAC) for both main terminal polarities. This must be done by measuring the voltage across R_4 at the instant of firing and then applying Ohm's Law to R_4. The scope must be connected to display the V_{R4} waveform. Compare measured I_{GT} to the manufacturer's specifications, if available.

   Measure V_{TM}, the voltage across the TRIAC after firing. Compare to the manufacturer's specifications, if available.

3. Heat the TRIAC with a soldering iron and note the effect on the firing delay angle. — — — —

4. Substitute different TRIACs of the same type number. Repeat the procedure and describe the results. — — — —

Insert a DIAC in the gate lead of the TRIAC. Use a TI43A DIAC or any equivalent DIAC with about the same breakover voltage rating (32V). Change the following component sizes; leave everything else the same.

R_2 = 200K

R_3 = 4.7KΩ

C_1 = 0.1μF

C_2 = 0.02μF

5. Are the firing delay angles the same for both half cycles? — — — —

   Why?

6. Heat the TRIAC with the tip of a soldering iron. Explain the results. — — — —

7. Substitute different TRIACs of the same type number and note the effect on firing symmetry and gate current requirements. — — — —

8. Clean up area and return tools and materials. — — — —

Average of above evaluations* — — — —

*This average is the student's final evaluation for competencies D9, D11 and D15.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XI: THYRISTORS

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. An SCR is normally turned on by which of the following?

a. Anode-to-cathode voltage
b. Anode-to-cathode current
c. Cathode voltage
d. Gate current
e. Gate resistance

____ 2. Regardless of gate current, which describes voltage from anode to cathode that causes current to flow?

a. R_{GT}
b. I_{GT}
c. V_{GT}
d. V_F
e. V_{BO}

____ 3. When an SCR is on, what is the ideal anode-to-cathode voltage equal to?

a. 0 volts
b. The source voltage
c. The gate voltage
d. ±12 volts
e. ±7 volts

____ 4. When an SCR is off, what is the ideal anode current equal to?

a. The gate current
b. The supply current
c. 0 amps
d. ±50 mA
e. ±10mA

____ 5. In which circuit would an SCR most likely be found?

a. Control circuit for a DC motor
b. Oscillator circuit
c. FM amplifier circuit
d. Microprocessor circuit
e. Memory device

____ 6. What is the amount of current called that is required to keep a TRIAC turned on?

a. Breakover point
b. Reverse breakover point
c. Holding current
d. Gate current
e. Full current

____ 7. Which describes the voltage between the main terminals when a TRIAC is turned on?

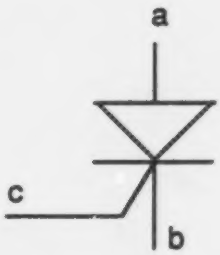
a. As high as possible
b. Equal to source voltage
c. Equal to load voltage
d. As low as possible
e. Equal to half the load voltage

____ 8. How is a TRIAC different from an SCR?

a. Has more terminals
b. Can conduct in either direction
c. Has a lower breakover point
d. Consumes more power
e. Consumes less power

____ 9. Which device is used to make the TRIAC fire more consistently?

a. SCR
b. Higher voltage supply
c. DIAC
d. Rheostat
e. Timing capacitor



____ 10. On the illustration, which point represents the cathode of an SCR?

____ 11. Which point represents the gate?

____ 12 Which does not help reduce the thermal resistance between an SCR's case and sink?

a. Keep surfaces as smooth as possible.
b. Keep surface areas between the two high.
c. Use thermal joint compound.
d. Apply only recommended tightening torques.
e. Transfer heat through the ambient to the heat sink.

ANSWERS TO UNIT TEST

1.	d	(D10)
2.	e	(D10)
3.	a	(D10)
4.	c	(D10)
5.	a	(D16)
6.	c	(D11)
7.	d	(D11)
8.	b	(D11)
9.	c	(D9)
10.	b	(D10)
11.	c	(D10)
12.	e	(D16)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS
UNIT XII: THREE-TERMINAL REGULATOR

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to explain the operation and application of the three-terminal regulator and the selection criteria to use when choosing a replacement. The student should be able to identify the terminals of the regulator using manufacturer's literature. This knowledge will be evidenced by achieving a specified score on the job sheets and unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Define terms and definitions.

1.2 Compute current or voltage regulation.

1.3 Using manufacturer's literature, select replacement three-terminal regulators based upon circuit needs and the three-terminal regulator's capabilities and limitations. (competencies C5, D16)

1.4 Identify other types of regulators. (competencies C5-7)

1.5 Construct and test a three-terminal regulator. (partial competency C5, JS 1.1)

1.6 Measure ripple rejection of a three-terminal regulator. (partial competency C9, JS 1.2)

1.7 Test the constant-current regulator. (competency C6, JS 1.3)

1.8 Test the three-terminal adjustable-voltage regulator. (competencies C5 and C9, JS 1.4)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XII: THREE-TERMINAL REGULATOR

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

1. Lesson 1: THREE-TERMINAL REGULATOR

    a. Information outline

    b. Transparency masters

        TM 1.1: Three-terminal regulator (fixed mode)
        TM 1.2: Three-terminal regulator (adjustable mode)
        TM 1.3: Three-terminal current regulator

    c. Job sheets

        JS 1.1: Construct and test a three-terminal regulator
        JS 1.2: Measure ripple rejection of a three-terminal regulator
        JS 1.3: Test the constant current regulator
        JS 1.4: Test the three-terminal adjustable-voltage regulator

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Linear Integrated Circuits. 38th ed. San Diego: D.A.T.A., Inc., 1987.

2. Adamson, Thomas A. Electronic Communication Systems and Circuits. Albany, NY: Delmar, 1988.

3. Gottlieb, Irving M. Power Control With Solid State Devices. Reston, VA: Reston Publishing, 1985.

4. Grob, Bernard. Electronics: Electronic Circuits and Applications. New York: McGraw-Hill Book Co., 1982.

B. Audiovisuals

1. "Switching Power Supplies". Electronics Industries Association (EIA).

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Explain that the trend is away from circuits that have discrete components (capacitors, inductors and transistors) due to cost and reliability of those circuits.

2. Contrast the number of components in any of the newer adjustable power supplies with the number of components in an older unit.

3. Allow flexibility on the part of the student. The job sheets open avenues for student experimentation. Encourage the student to build or modify the designs and observe the results.

4. Demonstrate three-terminal regulator terminal identification and looking up the regulator in manufacturer's literature.

5. Discuss thermal conduction and heat sinks with the students.

B. Suggested student activities

1. Encourage students to make their own bench-top adjustable power supply. This would be useful for anyone interested in electronics, and all of the necessary components are readily available at a moderate price.

2. This is an excellent time to examine the heating effects of power handling equipment and the importance of thermal conduction and thermal transfer.

C. Suggested supplemental material

1. Manufacturer's literature for three-terminal regulators

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XII: THREE-TERMINAL REGULATOR

LESSON 1: THREE-TERMINAL REGULATOR

I. Terms and definitions

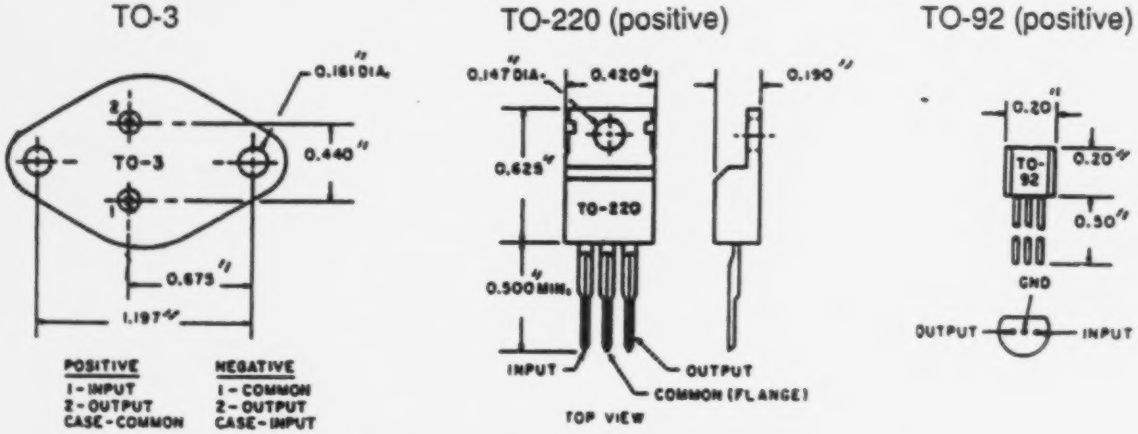
A. Regulation--sustaining the output of the source, voltage or current at a constant level by adjusting the level of the remaining quantity (voltage or current); expressed as percent of output change

B. Series regulator--component placed in series with the power supply's output to maintain a constant output voltage by controlling the current

C. Shunt regulator--component placed in parallel with the power supply's output and the load; maintains a constant output voltage by controlling the current; capable of passing the maximum current demanded by the load

D. Switching regulator--series device that is turned on and off at a high rate

E. Three-terminal regulator--complete, integrated-circuit and series regulator that governs voltage by varying current through it



TO-3 TO-220 (positive) TO-92 (positive)

0.161 DIA.
2
TO-3
1
0.440"
0.675"
1.197"
POSITIVE
1 - INPUT
2 - OUTPUT
CASE - COMMON
NEGATIVE
1 - COMMON
2 - OUTPUT
CASE - INPUT
0.147 DIA.
0.420"
0.190"
0.625"
TO-220
0.500 MIN.
INPUT
OUTPUT
COMMON (FLANGE)
TOP VIEW
0.20"
0.20"
TO-92
0.50"
GND
OUTPUT
INPUT

Three-terminal regulator diagrams

Credit: SK Series Solid State Replacement Guide. Deptford, NJ: RCA Corp., 1985.

II. Regulation

A. Voltage or current can be regulated.

B. Current is varied to achieve voltage regulation, while voltage is varied to achieve current regulation.

C. Regulation can be defined as the percent of output change as a function of the input voltage or output current change.

$$\% \text{ regulation} = \frac{\Delta \text{ voltage out}}{\Delta \text{ voltage in}} \times 100\%$$

III. The three-terminal regulator (TM 1.1-1.3)

A. An integrated circuit

B. Terminal identification

C. Fixed-voltage three-terminal regulators

1. Voltage regulator identification

2. Polarity of output

3. Current handling capabilities

4. Reading and interpreting manufacturer's literature

5. Response speed

6. Efficiency compared with discrete component regulators

D. Applications of the three-terminal regulator

1. Fixed-voltage regulator. Voltage is determined by the internal design of the device.

2. Adjustable voltage regulator

3. Current regulator

4. Filters ripple from the power supply (ripple rejection)

a. The three-terminal regulator can sense voltage changes in the microvolt region because of its fast action.

b. These small changes in voltage can be in the form of ripple.

c. The three-terminal regulator responds to these changes and levels voltage changes in the same way as a conventional filter circuit, but with less weight and cost.

5. Three-terminal regulators require an input voltage that is higher than the output voltage (typically 1-2V).

E. Heat dissipation, heat sink and ventilation considerations

F. Adjustable-voltage regulators

1. The three-terminal regulator can be installed in a circuit to provide a range of output voltages that is externally adjustable. Examples of such an arrangement can be found in almost all of the newer, inexpensive DC power supplies.

2. The fixed regulator can be made adjustable by adding an external voltage-divider network.

3. External controls needed

4. The minimum voltage output will not go to zero.

a. The most common minimum value is 5 volts.

b. The variable-regulation system circuit will not provide an output voltage less than the fixed-regulation value of the regulator.

5. Maximum voltage available

G. Current regulation

1. The three-terminal regulator can be connected to operate as a constant current source.

2. The unit operates as a constant voltage source, but feedback from the output to the regulator input terminal will be across a resistor. The value of the resistor is selected to provide the regulation voltage across it as the desired current passes through it.

Example: If a 5-volt regulator is to provide an output current of .1 amp, the feedback resistor selected would be 50Ω. (5V / .1 amp = 50)

3. Two important considerations must be observed.

a. The regulator must be capable of delivering the amperage.

b. The wattage of the feedback resistor must be capable of handling the heat generated.

4. Series regulator resistor

a. Value

b. Wattage

5. Adjustable current regulator

IV. Other types of regulators

A. The series regulator must be capable of passing the maximum current demanded by the load.

B. Shunt regulators achieve regulation by maintaining a constant current out of the power supply rectifier section.

C. Switching regulator

1. The switching device is never in the heat-producing, intermediate conduction region.

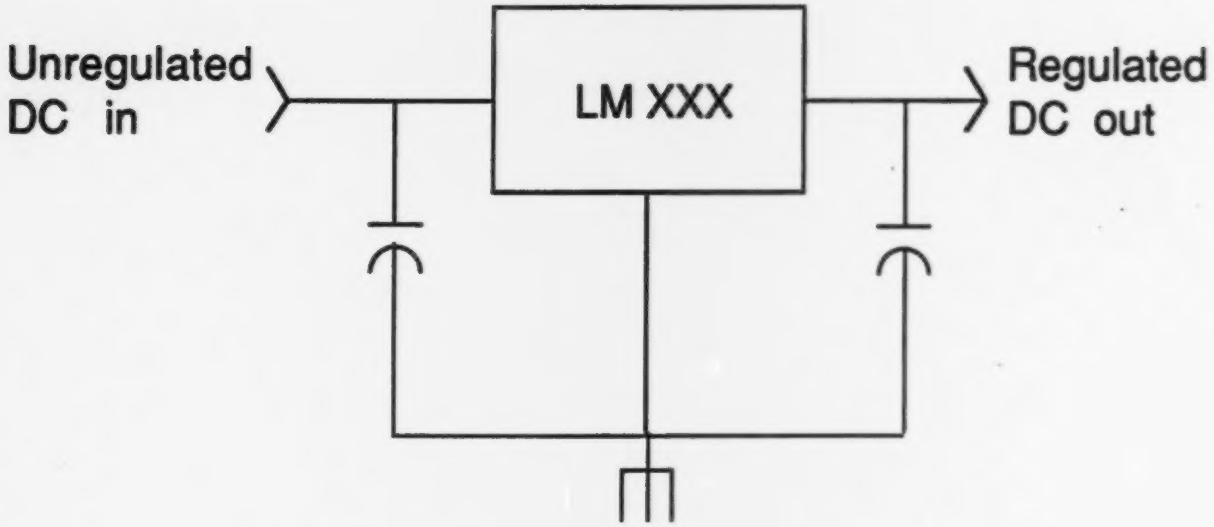
2. It is either turned full off or full on and thereby is always in the most efficient mode of operation, producing minimum heat.

3. Regulation is achieved by varying the on-off duty cycle.

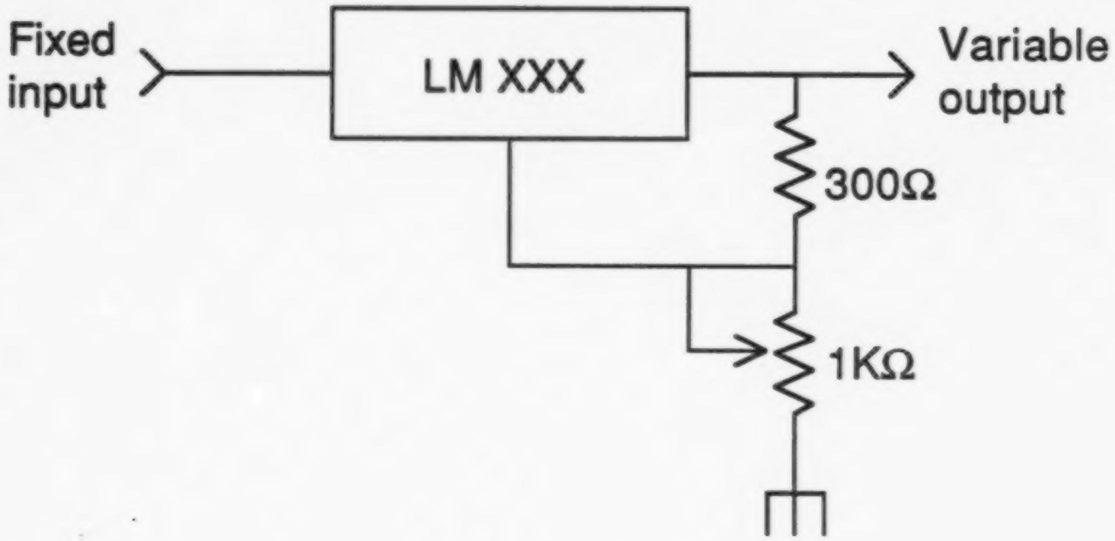
4. Typically, the switching rate of this system will be around 20KHz.

5. The output of the switching supply will be a high-frequency square wave that is easily filtered using capacitors.

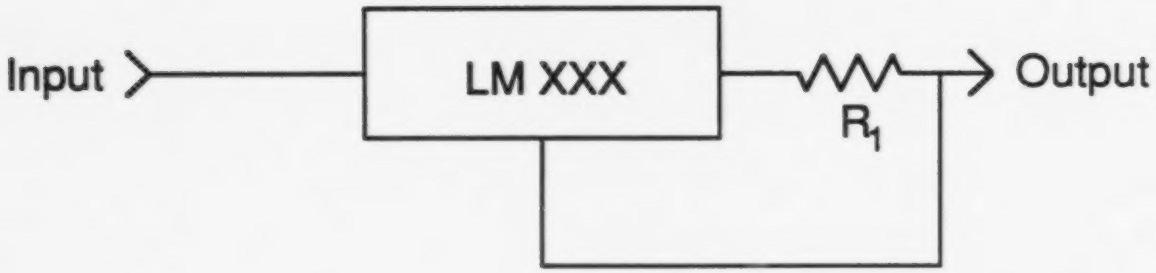
THREE-TERMINAL REGULATOR (FIXED MODE)


Unregulated
DC in
LM XXX
Regulated
DC out

THREE-TERMINAL REGULATOR (ADJUSTABLE MODE)


Fixed input
LM XXX
Variable output
300Ω
1KΩ

THREE-TERMINAL CURRENT REGULATOR



NOTE: The value of R_1 will be selected so that the desired current times R_1's value will equal the three-terminal regulator's voltage regulation value.

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CONSTRUCT AND TEST A THREE-TERMINAL REGULATOR

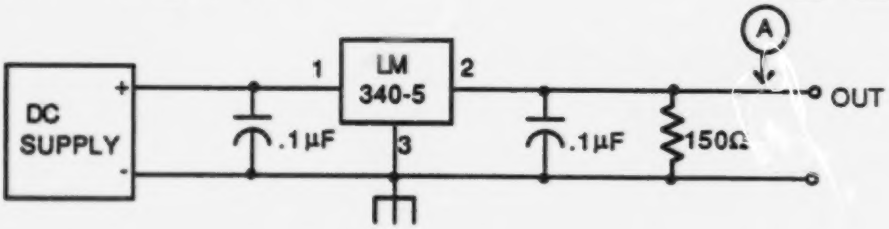
Equipment:

DC power supply, adjustable to 18 volts and 1.5 amps
LM340-5
Resistors: 150Ω, 10KΩ, two 560Ω, 1KΩ, 470Ω, 330Ω
2.5KΩ potentiometer
Capacitors: 1 μF, 25 volts (2)
12-volt bayonet or other low-wattage lamp

Procedure:

Evaluation
3 2 1 N

1. Construct the following circuit. _ _ _ _



2. Adjust the DC power supply to each of the output voltages listed in the table and measure and record the current and voltage output. _ _ _ _

DC supply output	E_{out}	I_{out}	% regulation
2V			
4V			
6V			
8V			
10V			
12V			
14V			

3. Calculate and record the percent regulation at each DC supply voltage in the previous chart. Assume that 10 volts is the reference point for all output changes. _ _ _ _

What was the range of input voltages in which the output remained within regulation?

4. Look up the LM340-5 in the reference manual. What is the range of input voltages that this device should remain within regulation? — — — —

Did this device meet the specifications?

5. Return equipment to its proper storage location. — — — —

Average of above evaluation*

*This average is the student's partial evaluation for competency C5: Identify and describe use of series regulators.

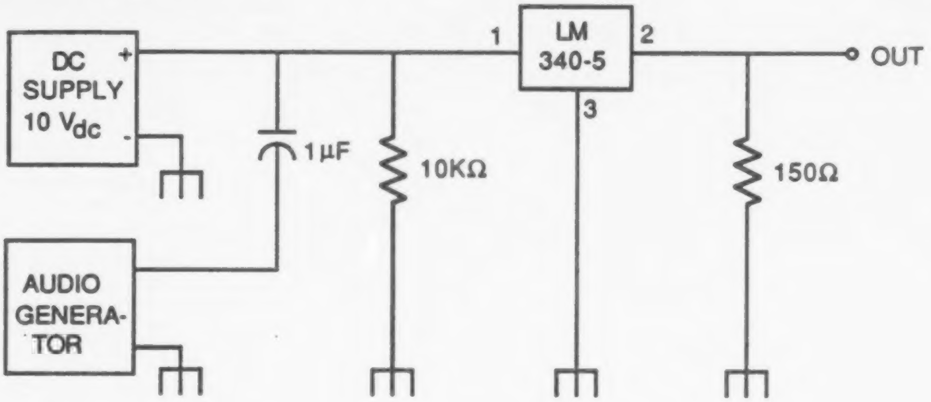
MEASURE RIPPLE REJECTION OF A THREE-TERMINAL REGULATOR

Equipment:

DC power supply, adjustable to 18V and 1.5A
LM340-5
Resistors: 150Ω, 1/2 watt
10KΩ, 1/2 watt
2.5KΩ potentiometer

Capacitors: 1 μF, 25 volts (2)
12V bayonet or other low-wattage lamp
Audio oscillator
Oscilloscope
General-purpose cross-reference manual

Procedure:	Evaluation 3	2	1	N
1. Connect the following circuit to determine the ripple rejection of the three-terminal regulator.	___	___	___	___



2. Adjust the audio generator for a $1V_{P-P}$, 0.1KHz signal at terminal 1 (input) of the LM340.	___	___	___	___
3. Measure and record the output AC signal. (Pin 3 of the LM340)	___	___	___	___
4. Calculate and record the percentage and dB ripple rejection of the device using the formula below.	___	___	___	___

$$\frac{\text{Ripple out}}{\text{Ripple in}} \times 100\%$$

% = ______________ % = ______________

dB = ______________ dB = 20 log

5. Look up the LM340 in the reference manual. What is the minimum and the normal rejection ratio of this device? _ _ _ _

minimum ________________ dB

normal ________________ dB

Did this device meet specifications?

6. Return equipment to its proper storage location. _ _ _ _

Average of above evaluation*

*This average is the student's partial evaluation for competency C9: Test power supply and correct defects.

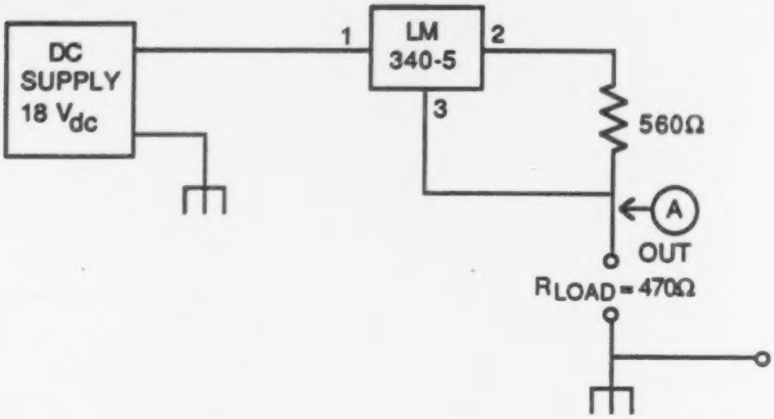
TEST THE CONSTANT-CURRENT REGULATOR

Equipment:

DC supply to 18V at 1.5A
LM340-5 regulator
Resistors: 560Ω, 1W
470Ω, 1W

Procedure:

	Evaluation			
	3	2	1	N
1. Connect the LM340 to operate as a constant-current, variable-voltage regulator as shown below.	__	__	__	__



2. For each value of R_{load}, measure and record E_{out}, E_{load}, I_{load} and the voltage from terminals 2 and 3 of the LM340-5.	__	__	__	__

R_{load}	E_{out}	E_{load}	I_{load}	E term 2-3
1K				
560				
470				
330				
150				

Why did I_{load} remain constant as the value of R_{load} was changed?

3. What is the maximum current that can be safely demanded from the regulator used in this procedure?	__	__	__	__

What precaution is to be followed if the regulator is to be used at or near the maximum current rating?

4. Return equipment to its proper storage location. ___ ___ ___ ___

Average of above evaluation*

*This average is the student's final evaluation for competency C6: Identify and describe use of shunt regulators.

JS 1.4

TEST THE THREE-TERMINAL ADJUSTABLE-VOLTAGE REGULATOR

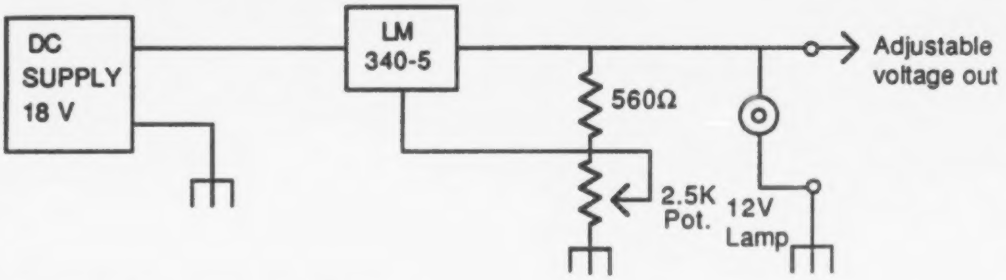
Equipment:

DC power supply to 18V at 1.5A
LM340-5 regulator
560Ω, 1/2W resistor
12V lamp
Electrical socket
2.5KΩ, 1/2W potentiometer

Evaluation
3 2 1 N

Procedure:

1. Construct the following adjustable-voltage circuit. ___ ___ ___ ___


DC
SUPPLY
18 V
LM
340-5
560Ω
2.5K
Pot.
12V
Lamp
Adjustable
voltage out

2. Set R_2 to a minimum value of resistance. ___ ___ ___ ___
3. Record the output voltages and lamp indications in the table below. ___ ___ ___ ___

R_2 value	ER_2	IR_2	ER_1	IR_1	E_{out}	Lamp
Minimum						
500						
1K						
1.5K						
2K						
Maximum						

4. Measure and record the voltage across R_2 and R_1. ___ ___ ___ ___
5. Calculate and record the current through R_2 and R_1. ___ ___ ___ ___

6. Repeat steps 3-5 for each value of R_2 in the table. From your observations, as R_2 was varied, what happened to the current through R_1? — — — —

To minimize heat losses in the system, what could be done to the values of R and R_2?

7. Return equipment to its proper storage location. — — — —

Average of above evaluation* — — — —

*This average is the student's final evaluation for competencies C5 and C9.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XII: THREE-TERMINAL REGULATOR

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which of the following is not a use of the three-terminal regulator?

a. As a fixed voltage source
b. As a ripple filter
c. As a frequency regulator
d. As a constant current source
e. All of the above

____ 2. How many resistors are required to make the three-terminal regulator into a constant-current source?

a. 1
b. 2
c. 3
d. 4
e. 5

____ 3. Which is the formula for computing percent regulation?

a. $\frac{\Delta \text{ voltage out}}{\Delta \text{ voltage in}} \times 100\%$

b. $\frac{\Delta \text{ voltage in}}{\Delta \text{ voltage out}} \times 100\%$

c. $\frac{\Delta \text{ voltage out}}{\Delta \text{ voltage in}} \times 50\%$

d. $\frac{\Delta \text{ voltage in}}{\Delta \text{ voltage out}} \times 50\%$

e. None of the above

____ 4. Why are filter capacitors required on the output of the three-terminal regulator?

a. The regulator cannot respond to voltage changes.
b. The regulator controls the effective value of voltage.
c. The regulator does not require filter capacitors.
d. Capacitors compensate for internal inductances.
e. None of the above

____ 5. Which regulator operates either completely on or off and has a high-frequency square wave output?

a. Series
b. Switching
c. Shunt
d. Adjustable voltage
e. Three terminal

____ 6. What are the essential considerations when using the three-terminal regulator as a constant current source?

a. Heat dissipation of the regulator tab and the resistor lead length
b. Resistance value of the feedback resistor and the regulator power
c. Ventilation of the chassis and the current desired
d. Power rating of the feedback resistor and regulator current rating
e. All of the above

____ 7. An LM340-5 is used in an adjustable control circuit, and the power supply has an unregulated output of $30V_{DC}$. What is the minimum regulated voltage output that can be obtained?

a. 30V
b. 26V
c. 15V
d. 10V
e. 5V

____ 8. Which of the following is placed in parallel with the power supply's output and the load to maintain a constant output voltage?

a. Series regulator
b. Shunt regulator
c. Switching regulator
d. Three-terminal regulator
e. All of the above

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ANSWERS TO UNIT TEST

1. c (C5)
2. a (C6)
3. a
4. c (C5)
5. b (C7)
6. d
7. e (C9)
8. b (C6)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XIII: OSCILLATORS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to describe the requirements for electronic oscillation and identify three of the more common oscillator circuits. This knowledge will be evidenced by achieving a specified score on the job sheets and unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Identify terms and definitions related to oscillators.

1.2 Describe oscillation principles and requirements.

1.3 Identify common oscillator circuits. (competencies F1, F2, F4)

1.4 Demonstrate the ability to:

  a. Construct Wien-bridge oscillator. (competencies F1 and F4, JS 1.1)
  b. Construct R-C frequency-controlled oscillator. (competencies F5, F7 and H4, JS 1.2)
  c. Describe the basic operation of a crystal oscillator. (competencies F2 and H4, JS 1.3)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XIII: OSCILLATORS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

1. Lesson 1: OSCILLATOR REQUIREMENTS

    a. Information outline

    b. Transparency masters

        TM 1.1: Crystal-controlled oscillator
        TM 1.2: Oscillator power supply (R-C phase shift)
        TM 1.3: Twin-T oscillator
        TM 1.4: Wien-bridge oscillator

    c. Assignment sheet

        AS 1.1: Oscillators

    d. Answers to assignment sheet

    e. Job sheets

        JS 1.1: Construct Wien-bridge oscillator
        JS 1.2: Construct R-C frequency-controlled oscillator
        JS 1.3: Describe the basic operation of a crystal oscillator

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Adamson, Thomas A. Electronic Communication Systems and Circuits. Albany, NY: Delmar, 1988.

2. Miller, Gary M. Modern Electronic Communication. 3rd ed. Englewood Cliffs, NJ: Prentice Hall, 1983.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Explain the variety of oscillator applications, such as broadcast communications, television receivers and other consumer electronics devices, computers, pulse generators and testing equipment.

2. Make sure that the students are familiar with the basic waveforms available from modern signal generators.

3. Field trips and examination of school-owned equipment is encouraged.

B. Suggested student activities

1. Examination of the waveforms produced by waveform generators and the human voice is appropriate.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XIII: OSCILLATORS

LESSON 1: OSCILLATOR REQUIREMENTS

I. Terms and definitions

   A. Barkhausen criterion--In order for oscillation to occur, the product of the amplifier gain and the signal feedback (from output to input) must equal unity.

   B. Buffer--an amplifier that is connected between the oscillator and the load. The buffer is used to keep the load from pulling the oscillator off frequency.

   C. Harmonics--Oscillator frequencies are frequently doubled, tripled or multiplied by a higher value. These multiples of the basic oscillator frequency are called harmonics.

   D. Oscillator--an electronic circuit that can produce its own waveform

   E. Positive feedback--To reinforce the output, a portion of an amplifier's output is connected to the input.

II. Oscillator principles

   A. The oscillator is the foundation of all radio transmission and receiving systems.

   B. It provides a signal at some frequency or range of frequencies.

   C. Classification (TM 1.1)

      1. According to the range of frequencies that it produces

      2. According to the method of frequency production

      Examples: The frequency reference can be an R-C network, an L-C tuned circuit or a crystal. Additionally, the oscillator can be externally controlled by a method called frequency synthesis.

         a. Radio transmitters and receivers require a precision frequency reference. This is commonly accomplished by using the crystal, which is purchased to operate at some specific frequency and will normally maintain that frequency within a few parts per million (ppm).

         b. Since the crystal has a fairly high temperature coefficient, if extreme precision is required, the crystal can be kept in a heated constant-temperature chamber.

   D. Oscillator requirements

      1. Source of energy--the power supply

      2. A frequency-determining circuit

      3. An amplifier

      4. A positive feedback

III. Resistance-capacitance (R-C) phase-shift oscillators **(TM 1.2)**

A. Phase-shift oscillator

1. These oscillators use three R-C networks to produce the necessary 180° phase reversal to provide positive feedback.

2. The three R-C networks (CF, RF; CF_2, RF_2; CF_3, RF_3) each contribute approximately a 60° phase shift for a total of 180°.

   a. This 180° phase shift provides an input to the FET that reinforces the output, thus providing the necessary positive feedback necessary for oscillation.

   b. The values of R_D, R_S and C_S provide bias necessary to establish gain.

3. Formula for determining frequency: $fr = \frac{1}{2\pi \sqrt{6}\, RC}$

B. Twin-T filter **(TM 1.3)**

1. This filter produces a lead lag network where the proper phase shift occurs at the desired frequency.

2. Positive feedback occurs at a frequency determined by the values of R_1, C_1, R_2 or C_2. This positive feedback is applied to the non-inverting inputs of the amplifier.

   a. The amplitude of the output is controlled by the amplifier's gain.

   b. Adjustable resistor R_4 and fixed resistor R_3 control the gain by controlling the feedback to the amplifier's inverting input.

3. Formula for oscillation: $fr = \frac{1}{2\pi RC}$

C. Wien-bridge oscillator **(TM 1.4)**

1. Uses a variable resistor to maintain a frequency

2. Popular because of its low cost and good stability

3. The combination of CF and RF in series and in parallel provide the 180° phase shift back to the input that is necessary to start oscillation.

   a. The combination of resistors R and 2R provide the gain necessary to sustain oscillations.

   b. By varying the value of resistor 2R, output amplitude can be controlled.

4. To estimate frequency of oscillation: $fr = \frac{1}{2\pi RC}$

   NOTE: R and C control the feedback RC rate.

5. The setting of the 10K potentiometer controls the degree and amplitude of oscillation.

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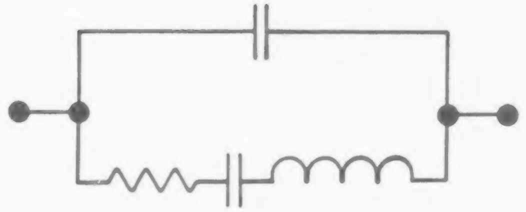
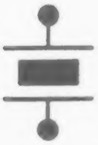
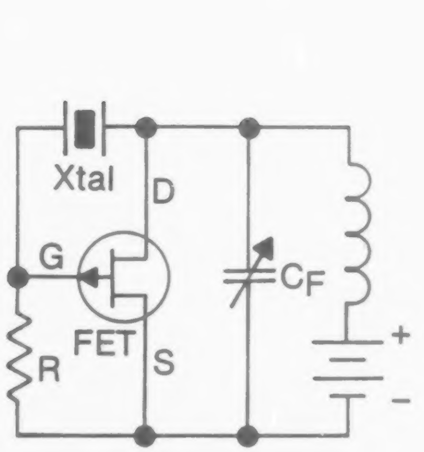
CRYSTAL-CONTROLLED OSCILLATOR



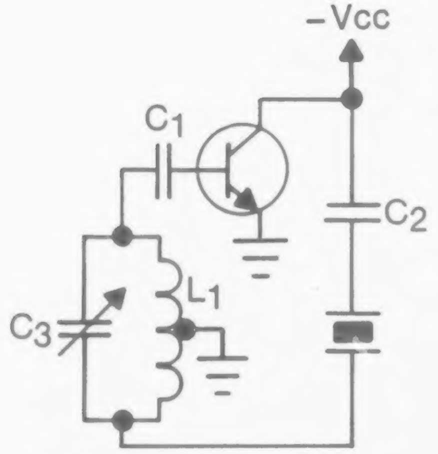
Crystal Equivalent Circuit



Crystal

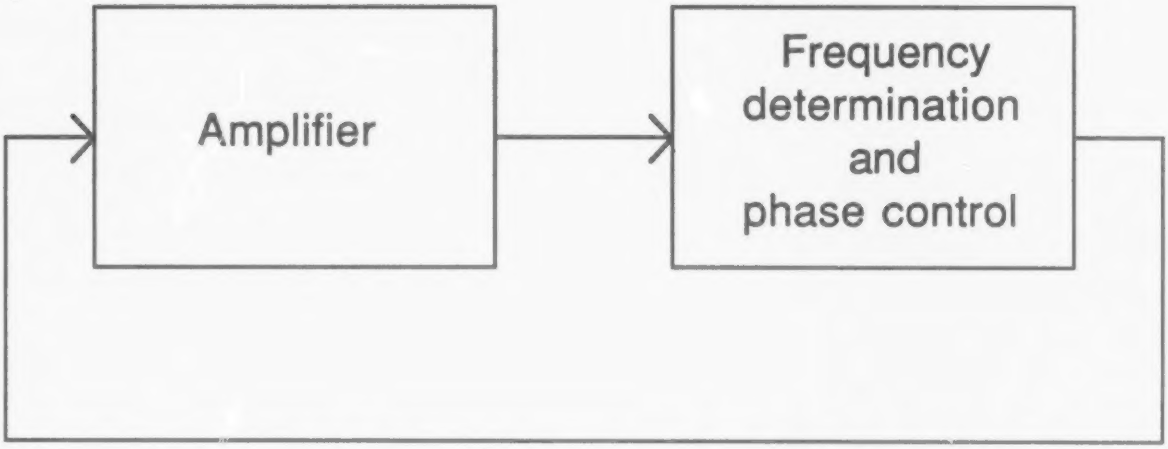

Xtal
D
G
FET
S
R
CF
+
-

Pierce Oscillator


-Vcc
C1
C2
L1
C3

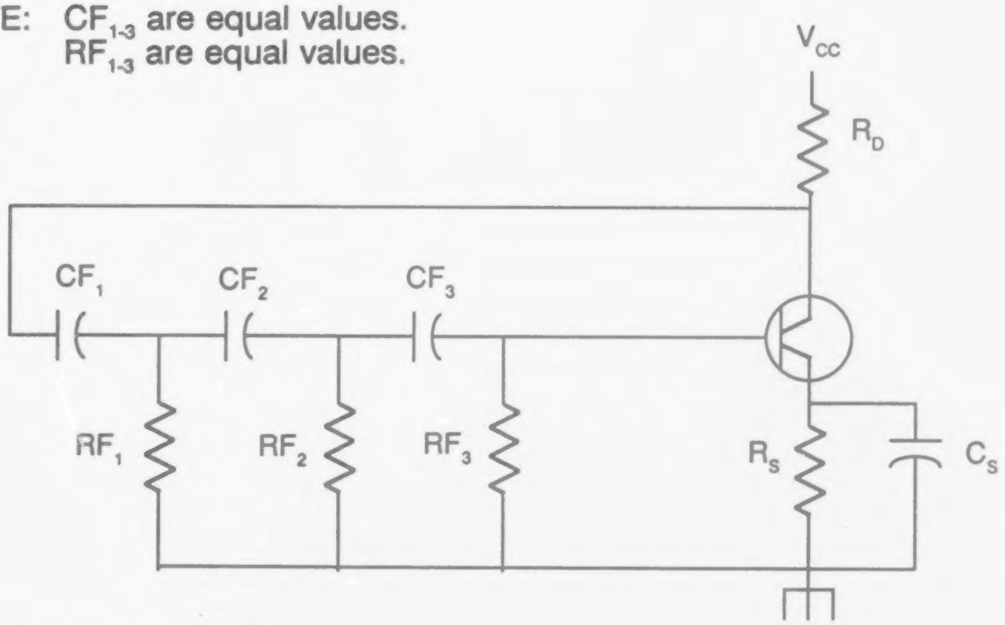
Crystal Controlled Hartley

OSCILLATOR POWER SUPPLY
(R-C PHASE SHIFT)


Amplifier
Frequency determination and phase control

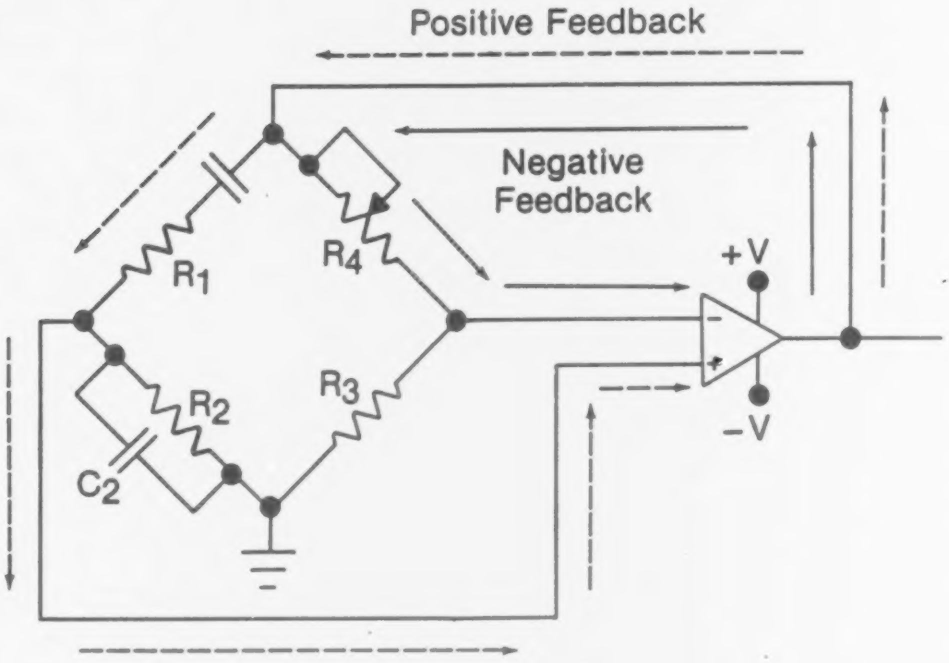
BASIC PHASE SHIFT OSCILLATOR

NOTE: $CF_{1\text{-}3}$ are equal values.
$RF_{1\text{-}3}$ are equal values.


V_{CC}
R_D
CF_1
CF_2
CF_3
RF_1
RF_2
RF_3
R_S
C_S

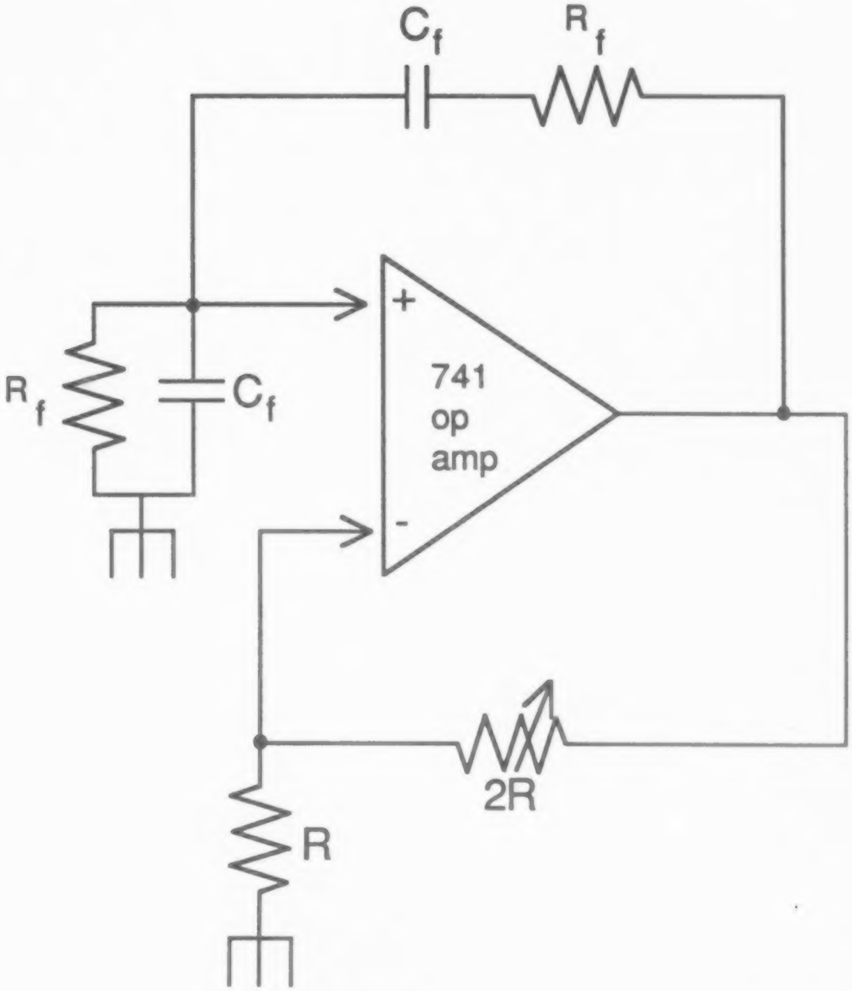
RC circuit

TWIN-T OSCILLATOR


Positive Feedback
Negative
Feedback
R1
R4
R2
R3
C2
+V
−V
−
+

- C_1, R_1, and C_2, R_2 Form The Frequency Determining Network
- R_3 and R_4 Develop The Degenerative Feedback

WIEN-BRIDGE OSCILLATOR


C
f
R
f
R
f
C
f
+
-
741
op
amp
2R
R

AS 1.1

OSCILLATORS

1. **State the four major components of any oscillation circuit.**

   a.

   b.

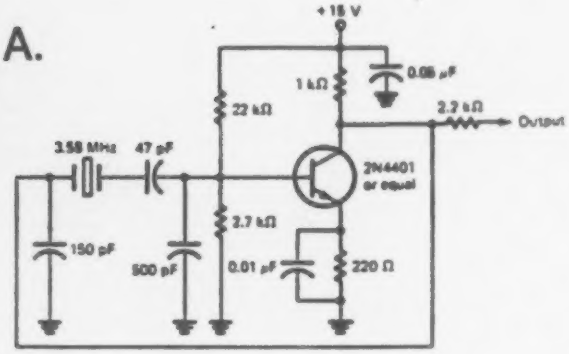
   c.

   d.

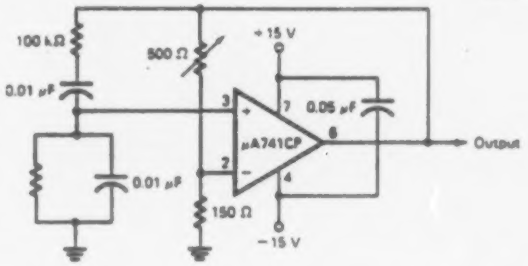
2. **What is the Barkhausen criterion?**

3. **What kind of oscillator is "A" below? _____ Is its frequency determining component an RC network, LC network or crystal? ___________**

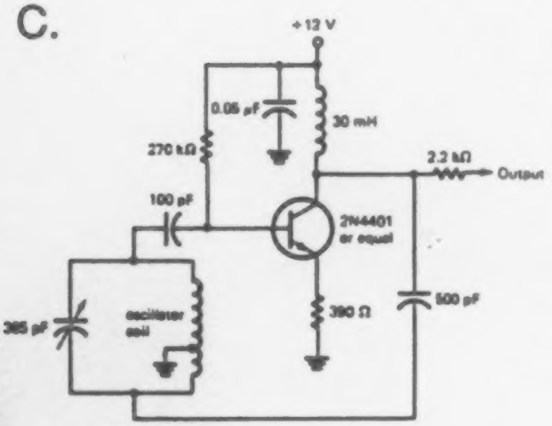
A.


+15 V
1 kΩ
0.05 μF
22 kΩ
2.2 kΩ
Output
3.58 MHz
47 pF
2N4401
or equal
2.7 kΩ
150 pF
500 pF
0.01 μF
220 Ω

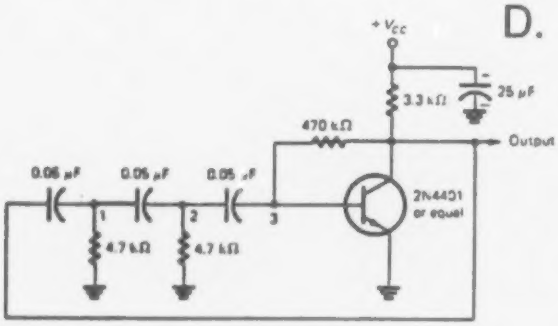
B.


100 kΩ
500 Ω
+15 V
0.01 μF
3
+
7
0.05 μF
6
μA741CP
Output
2
−
4
0.01 μF
150 Ω
−15 V

C.


+12 V
0.05 μF
30 mH
270 kΩ
2.2 kΩ
Output
100 pF
2N4401
or equal
365 pF
oscillator
coil
390 Ω
500 pF

D.


+V_{CC}
3.3 kΩ
25 μF
470 kΩ
Output
0.05 μF
0.05 μF
0.05 μF
1
2
3
2N4401
or equal
4.7 kΩ
4.7 kΩ

4. What kind of oscillator is "B"? ______ Is its frequency determining component an RC network, LC network or crystal? ____________

5. What kind of oscillator is "C"? ______ Is its frequency determining component an RC network, LC network or crystal? ____________

6. Lastly, what kind of oscillator is "D"? ______ Is its frequency determining component an RC network, LC network or crystal? ____________

ANSWERS TO AS 1.1

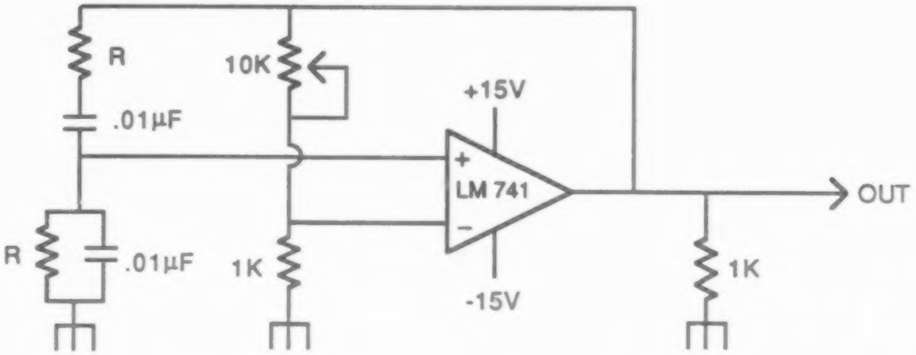
1. Source of energy (power supply), frequency determining circuit, amplifier, positive feedback circuit
2. The product of the amplifier gain and the signal feedback (from output to input) must equal unity.
3. Crystal, crystal
4. Wien bridge, RC network
5. Hartley, LC network (tank circuit)
6. Phase shift, RC network

CONSTRUCT WIEN-BRIDGE OSCILLATOR

Equipment:

LM741 op amp
Resistors, 1/2W: 1KΩ, (2)
10KΩ (2)
22KΩ (2)
33KΩ (2)
100KΩ (2)
10KΩ adjustable

Capacitors: .01μF, 16V (2)
.1μF, 16V (2)
DC power supplies, two at 15V and .25A
Oscilloscope, frequency response to 20mHz



Procedure:

Evaluation
3 2 1 N

1. Construct the circuit above. Use 10KΩ for R. — — — —
2. Calculate and record the expected frequency in the chart below. — — — —

Feedback R	Feedback C (μF)	Calculated freq. (H)	Measured freq. (H)	E output (P-P) Max.	E output (P-P) Min.
10K	.01				
22K	.01				
33K	.01				
33K	.1				
100K	.1				

3. Connect an oscilloscope to the output and adjust the 10K potentiometer until oscillation is evident. — — — —
4. Measure and record the frequency of oscillation. — — — —
5. Adjust the 10KΩ potentiometer to obtain the smallest possible output amplitude; record this value. — — — —

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6. Repeat step 5 for the greatest output amplitude. ___ ___ ___ ___

Did varying the 10KΩ potentiometer affect the output frequency?

____

What kind of feedback does the Wien-bridge oscillator require to sustain oscillation?

What kind of feedback is provided by the 10KΩ potentiometer?

7. Change the supply voltages from 15V to 10V. Did the output frequency change? ________ If so, by what percent? ________ ___ ___ ___ ___

8. Repeat steps 1-6 for each value of R and C in the table. ___ ___ ___ ___

9. Return equipment to its proper storage location. ___ ___ ___ ___

Average of above evaluation* ___ ___ ___ ___

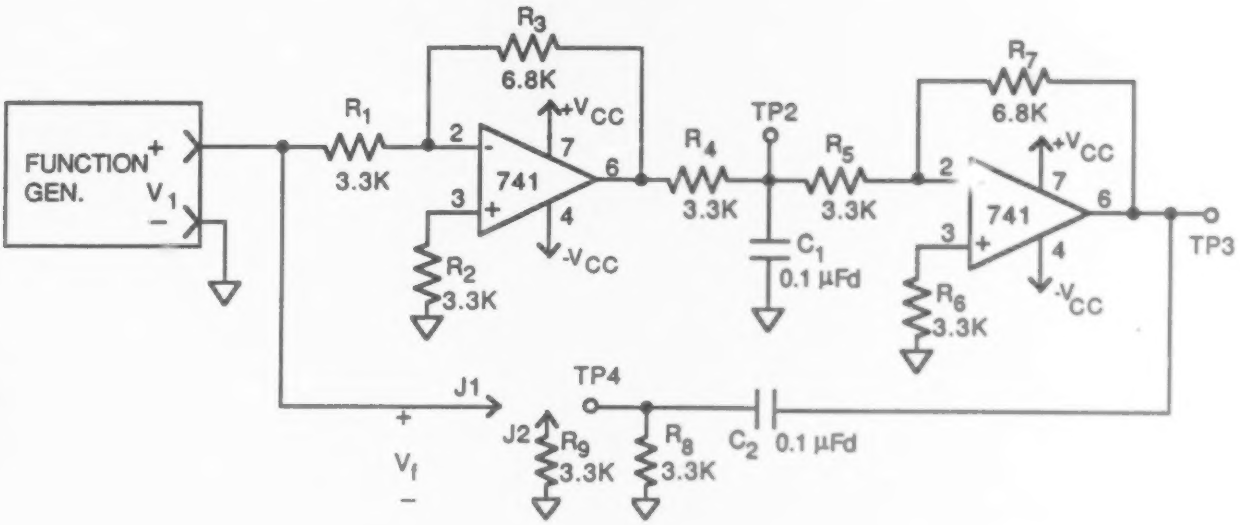
*This average is the student's partial evaluation for competencies F1 and F4.

CONSTRUCT R-C FREQUENCY-CONTROLLED OSCILLATORS

Equipment:

Dual-trace oscilloscope
Low-voltage power supply (2)
Function generator
Volt ohmmeter

Frequency counter
Prototype board
741 operational amplifiers (2)
Resistors: 3.3KΩ (7), 6.8KΩ (2)
Capacitors: 0.1μF (2)


FUNCTION GEN.
V_1
+
−
R_1
3.3K
R_2
3.3K
R_3
6.8K
741
2
3
4
6
7
$+V_{CC}$
$-V_{CC}$
TP2
R_4
3.3K
R_5
3.3K
C_1
0.1 μFd
R_6
3.3K
R_7
6.8K
741
TP3
J1
+
V_f
−
TP4
J2
R_9
3.3K
R_8
3.3K
C_2 0.1 μFd

Procedure:

Evaluation
3 2 1 N

1. Construct the circuit above. Connect the two power supplies to produce +V and -V as shown. Connect the function generator as V. ___ ___ ___ ___

2. Adjust the power supplies to provide +12V to the op amp. Connect R_9 to the output of the phase-shift network (C_2 & R_8) by connecting J_2 to TP4. ___ ___ ___ ___

   NOTE: This sets up the oscillator for open-loop operation. R_9 simulates the load that the amplifier would place on the lag network if the oscillator was running closed loop.

3. Perform a DC voltage check at TP2 and TP3 to verify that the op amp output voltage levels are at zero volts. ___ ___ ___ ___

4. Set the function generator controls to produce a 100mV sine wave at a frequency of 1KHz at the left side of R_1. Measure V_{TP1} and V_{TP3} at frequencies ranging from 500Hz to 2KHz. Determine the phase difference and lead-lag polarity between V_{TP1} and V_{TP3} at each of these frequencies. ___ ___ ___ ___

Frequency (Hz)	V_{TP1} (volts)	V_{TP3} (volts)	• (degrees)	Lead/lag (±)	Open loop gain

5. Test the oscillator for closed-loop operation. Disconnect the simulated load resistor, R_s, from TP4. Close the loop by connecting J_1 to TP4. Remove the function generator from the system. Measure the frequency of oscillation by connecting the frequency counter at TP3. — — — —

6. Sketch the resulting waveforms of the voltages at TP1, TP2, TP3 and TP4. Record the voltage amplitude and phase with each sketch. (The voltage at TP4 is the phase reference for measurements.) — — — —

7. Turn off both of the power supplies. Check to make sure that all required measurements have been recorded. — — — —

8. Disassemble the circuit and return equipment to its proper storage location. — — — —

9. Calculate and record the oscillator's loop gain (A x B) by dividing the open-loop output voltage, V, by the applied input voltage at each of the frequencies used in step 4. — — — —

Average of above evaluation* — — — —

*This average is the student's final evaluation for competency F5 and partial for competencies F7 and H4.

For discussion:

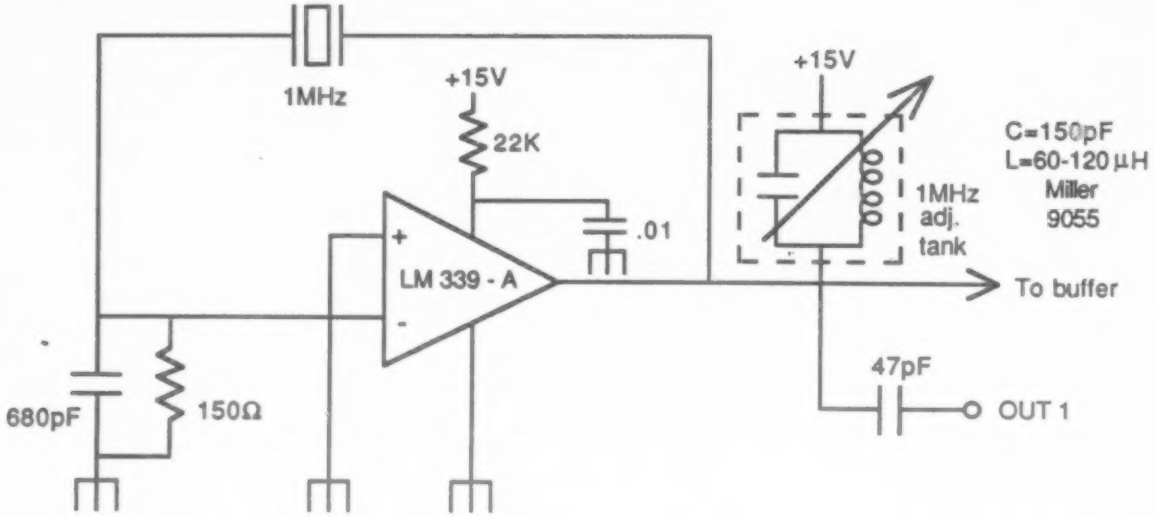
At what frequencies does the oscillator's measured loop gain exceed unity?
At what frequency does the open-loop phase difference between V and V equal zero degrees?
How do these frequencies compare to the frequency of oscillation measured in step 5?
What was the purpose of R_s in the open-circuit test circuit?
Why was 3.3K chosen as its resistance value?

JS 1.3

DESCRIBE THE BASIC OPERATION OF A CRYSTAL OSCILLATOR

Equipment:

DC power supply to 18V
Oscilloscope to 20mHz
Signal generator to 1mHz
Frequency counter, 21mHz
LM339A op amp
1mHz crystal
1mHz adjustable tank circuit
Capacitors: 680μF, 47μF, .01μF
Resistors: 150Ω, 22KΩ


1MHz
+15V
22K
.01
LM 339 - A
+
-
680pF
150Ω
+15V
1MHz
adj.
tank
C=150pF
L=60-120 μH
Miller
9055
To buffer
47pF
OUT 1

Evaluation
3 2 1 N

Procedure:

1. Construct the circuit above. ___ ___ ___ ___

   What will control the frequency of oscillation in this lab oscillator?

   What will cause the frequency to change?

2. Apply power to the circuit. Observe output #1 with an oscilloscope, channel A input. ___ ___ ___ ___

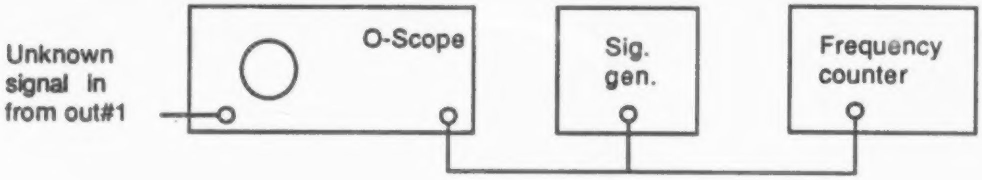
   NOTE: Use loose coupling. Direct connection of the probe will change the circuit output due to the probe capacitance.

3. Adjust the oscillator coil for a maximum output signal. — — — —

NOTE: Use a plastic tuning wand for the coil adjustment.

4. Measure and record the frequency of oscillation using a "zero beat" technique. (Description follows.) — — — —

a. Connect the following circuit.


Unknown signal in from out#1
O-Scope
Sig. gen.
Frequency counter

b. Operate the oscilloscope controls to observe a Lissajous pattern.

c. Adjust the signal generator for a stationary single-loop Lissajous pattern on the oscilloscope.

d. Measure the signal generator frequency with the frequency counter. (The frequency counter indication is the channel A input frequency.)

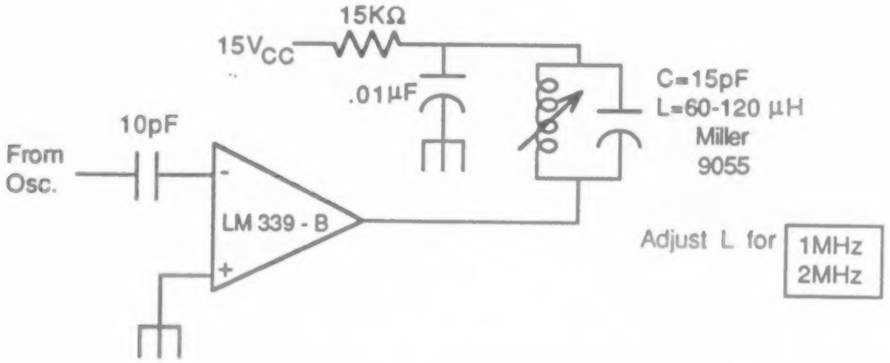
NOTE: You will notice slow rolling of the display due to instability in the oscillators involved. One roll per second equals an error of one cycle per second.

5. Heat the crystal by holding it between your fingers. What happened to the output frequency? ______________ Voltage? ___________ — — — —

6. Vary the supply voltage from 15V down to 11V DC. What effect did the supply voltage have on the output frequency? ______________ Voltage? ___________ — — — —

NOTE: This circuit is sensitive to external disturbances. For this reason, an amplifier stage called a buffer is commonly added to isolate the oscillator from the load. This buffer is often tuned to a harmonic (higher or lower) of the oscillator frequency.

7. Construct the buffer circuit below. — — — —


15KΩ
15V_CC
.01µF
C=15pF
L=60-120 µH
Miller
9055
10pF
From Osc.
-
LM 339 - B
+
Adjust L for
1MHz
2MHz

8. Connect the buffer input to the oscillator output. — — — —

9. Slightly adjust the oscillator tank coil for maximum signal at point 1. — — — —

10. Connect the oscilloscope to the buffer output 2. — — — —

11. Adjust the buffer coil for maximum voltage amplitude at the buffer output 2. — — — —

12. Measure and record the buffer output frequency ________ and voltage ________ . — — — —

Was the frequency output the same as the oscillator?

13. Connect the oscilloscope directly, then loosely coupled, to buffer output 2. — — — —

Did the buffer output frequency change during this step?

The buffer can be operated at some multiple of the oscillator by changing the values of C or the coil. The new frequency could be approximated by the formula:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$ when f = desired harmonic frequency

Using the formula, what value of C is appropriate for each of the following harmonics?
2nd f= 2mHz, C = ________
1/2 f= 500KHz C = ________
3rd f= 3mHz C = ________

14. Select the value of C necessary for a frequency doubler (f = 2 mHz) and replace the currently installed C with this new value. — — — —

15. Apply power and measure the output frequency ________ and voltage ________ . — — — —

What happened to the frequency stability?

How do you account for the apparent lack of stability in the buffer output frequency?

NOTE: It may be necessary to slightly adjust the buffer coil to produce the second harmonic.

16. Compare the buffer output voltage to the buffer output operating at the same frequency as the oscillator. — — — —

Basic frequency ________________ V_{P-P}
2nd harmonic ________________ V_{P-P}

17. Return equipment to its proper storage location. — — — —

Average of above evaluation* — — — —

*This average is the student's final evaluation for competencies F2 and H4.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XIII: OSCILLATORS

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which of the following oscillator circuits will provide the most precise frequency?

a. Crystal
b. Wien bridge
c. R-C
d. Colpitts
e. Twin-T

____ 2. Which principle states that in order for oscillation to occur, the product of amplifier gain and signal feedback must equal unity?

a. Oscillation principle
b. Barkhausen effect
c. Wien oscillator criterion
d. Pierce effect
e. Unity gain feedback principle

____ 3. Which of the following is not an oscillator requirement?

a. Power supply
b. Negative feedback
c. Positive feedback
d. Frequency-determining device
e. Amplification

____ 4. How much of a phase shift does the R-C oscillator require?

a. 45°
b. 90°
c. 180°
d. 270°
e. 360°

____ 5. Which oscillator circuit uses a variable resistor to adjust the frequency?

a. Colpitts
b. Pierce
c. R-C
d. Wien bridge
e. Twin-T

____ 6. In order to prevent loads from "pulling" the frequency of an oscillator, what is commonly added?

- a. Transformer link
- b. Capacitor coupling
- c. Buffer
- d. Twin-T filter
- e. Tank circuit

____ 7. What are frequencies that are multiples of an oscillator called?

- a. Channels
- b. Turned multiples
- c. Harmonics
- d. Octaves
- e. Subfrequencies

ANSWERS TO UNIT TEST

1.	a	(F2)
2.	b	(F1)
3.	b	(F1)
4.	c	(F4)
5.	d	(F1, 4)
6.	c	(F1, 4, 5, 7)
7.	c	(F2)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XIV: SERVICING BJT AMPLIFIERS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to demonstrate the proper procedure for troubleshooting multistage BJT amplifiers. Competencies will be demonstrated by achieving the specified score on the job sheet and unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Identify terms and definitions.

1.2 Explain the purpose of biasing techniques.

1.3 Using signal analysis and voltage techniques, identify the faulty stage in an amplifier system.

1.4 Test and repair bi-polar amplifier. (competency E4, JS 1.1)

1.5 Identify and replace semiconductor(s) on a circuit board. (competencies D16 and D17, JS 1.2)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XIV: SERVICING BJT AMPLIFIERS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: BJT SERVICING

   a. Information outline

   b. Assignment sheet

      AS 1.1: BJT AMPLIFIERS

   c. Answers to assignment sheet

   d. Job sheets

      JS 1.1: Test and repair bi-polar amplifier
      JS 1.2: Identify and replace semiconductor(s) on a circuit board

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Semiconductor Devices. Benton Harbor, MI: Heath Co., 1975.

2. Leonard, Vinclent F., Jr. Transistor Circuit Design. Heathkit Continuing Education. Benton Harbor, MI: Heath Co., 1983.

3. Oleksy, Jerome E. Electronic Troubleshooting. Indianapolis, IN: Bobbs-Merrill Educational Publishing, 1983.

4. Schuler, Charles A. Electronics: Principles and Applications. 2nd ed. St. Louis: McGraw-Hill, 1984.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

   1. Demonstrate identification of amplifier circuit configuration, biasing techniques and characteristics.

B. Suggested supplemental materials

   1. Schuler. Electric Circuit Applications. McGraw-Hill.

   2. Schuler, Charles A.; Richard J. Fowler. Basic Electricity and Electronics. St. Louis: McGraw-Hill, 1980.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XIV: SERVICING BJT AMPLIFIERS

LESSON 1: BJT SERVICING

I. Terms and definitions

- A. Beta (β or Hfe)--current gain of a BJT in a common emitter configuration. Beta is a ratio of the transistor's collector current and base current. $\beta = I_C / I_B$.
- B. Bias--DC voltages applied to the E-B and B-C junctions on a BJT to obtain the desired region of operation
- C. Distortion--undesired changes in the purity of an amplified signal
- D. Frequency response--a measure of gain verses frequency in an amplifier system
- E. Gain--increase in signal strength that takes place in the amplification of a signal
- F. Heat sink--mass of metal that is connected to a device to draw heat away from the device
- G. IF--(intermediate frequency) within a radio receiver, the frequency constant to which a signal transmission is converted
- H. Leaky--describes an undesirable current through a device
- I. RF--(radio frequency) frequencies at which electromagnetic radiation is possible (From 150 KHz to infrared is generally accepted.)
- J. Thermal stability--ability to keep a constant operation level as a transistor's temperature rises

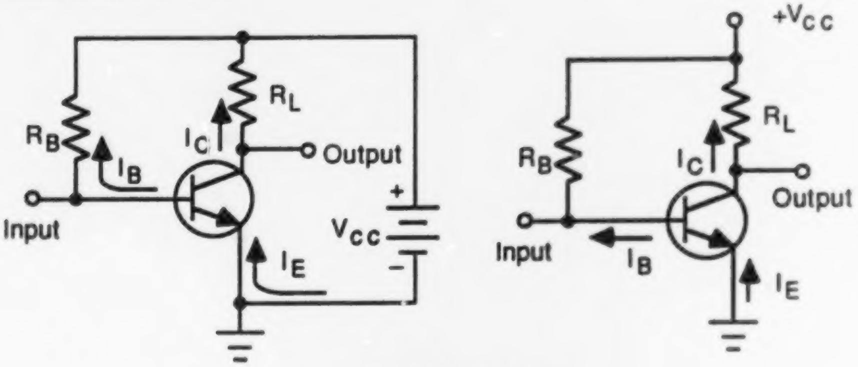
II. Biasing techniques

- A. Introduction
  1. Transistors must be biased for operation to provide good gain and low distortion.
  2. Small-signal amplifiers are biased for class A operation.
  3. Class A amplifiers are biased for middle-of-the-load line operation.
  4. Under normal operating conditions, Class A amplifiers have a collector voltage (V_C) of approximately one-half supply voltage for common emitter amplifiers.
  5. Two distinct biasing techniques are used to bias amplifiers.
     - a. Base bias
     - b. Voltage divider bias

  NOTE: Since common emitter amplifiers are the most widely used, the examples given will all be of this circuit configuration.

  6. These biasing techniques have some variation to allow for thermal stability.

B. **Base-biased amplifiers**



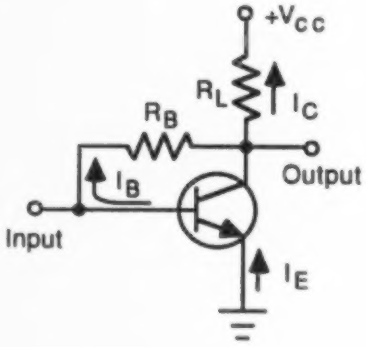
Base-biased amp

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

1. Base bias is sometimes referred to as fixed bias.
2. Base biasing uses a base resistor (R_B) connected to a supply voltage (V_{CC}) to bias the base.
3. Since the emitter lead is connected to ground and the E-B junction drops .6 volts, the emitter is at ground potential (0V) and the base voltage is .6V.
4. The resistance of R_B determines base current (I_B).
5. Resistor R_B drops V_{CC} minus the .6 volt drop of the E-B junction.
6. Base current (I_B) can be determined by dividing the voltage drop across R_B (V_{CC}-.6) by R_B.
7. Collector current equals I_B times the beta of the transistor.

NOTE: Beta is the current gain of the transistor. This specification can be found in a semiconductor replacement guide. (β or Hfe = I_C / I_B)

8. To allow for thermal stability, base voltage can be derived from the collector voltage by attaching R_B to the collector side of R_1.
9. This is called base bias with collector feedback.
10. Collector feedback provides negative or degenerative feedback for thermal stability.
11. If current increases through the transistor because of an increase in temperature, the following sequence of events takes place.
    a. Collector voltage (V_C) decreases.
    b. Voltage across R_B (V_{RB}) decreases.
    c. Base current (I_B) decreases.



Collector feedback

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

d. Collector current drops to compensate for temperature-induced current increase.

12. Another variation of base bias is base bias with emitter feedback.

13. The emitter resistor places emitter voltage (V_E) above ground potential.

14. This places base voltage (V_B) above .6V.

15. In this biasing technique, if current increases because of a temperature increase, the following events take place.

    a. Voltage drop across R_E increases.

    b. An N-type emitter becomes more positive.

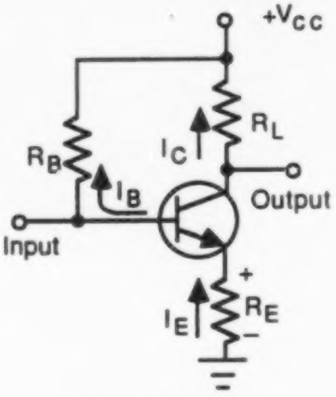
    c. A P-type base becomes more positive.

    d. R_B drops less voltage.

    e. Base current (I_B) decreases.

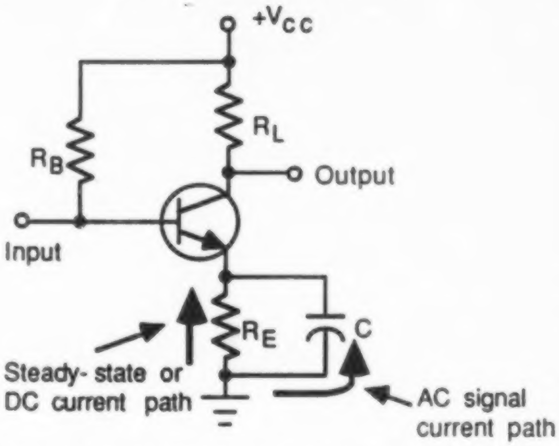
    f. Collector current decreases to compensate for the temperature-induced current increase.

16. To increase gain, an emitter bypass capacitor (C_E) can be added to the circuit to bypass the AC signal around R_E.


+Vcc
RL
IC
RB
IB
Output
Input
+
RE
IE
−

Emitter feedback

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.


+Vcc
RL
RB
Output
Input
RE
C
Steady- state or DC current path
AC signal current path

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

C. Voltage divider bias

1. Voltage divider bias uses a voltage divider network (R_1 and R_2) to set the base voltage (V_B).

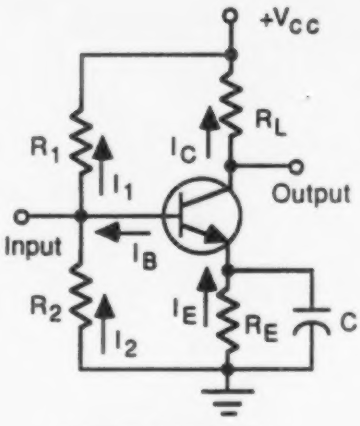
2. An emitter resistor (R_E) is required to set emitter current and protect the E-B junction from a base voltage greater than .6V.

3. Capacitor C is an emitter bypass capacitor used to increase the gain of the amplifier.

4. The value of R_1 determines collector voltage (V_C).

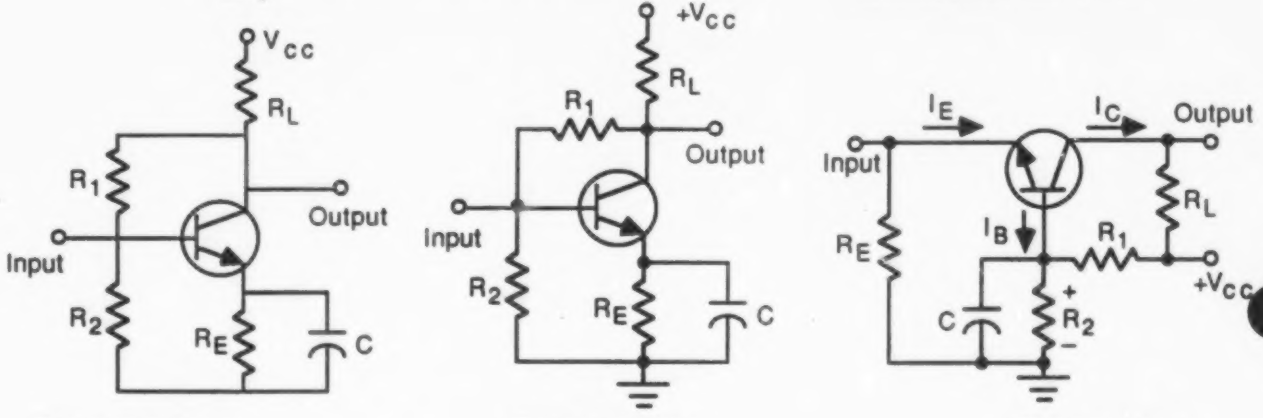
5. A variation of voltage divider biasing is voltage divider biasing with collector feedback.

6. Again, collector feedback is used to add thermal stability.



Voltage divider and emitter feedback

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.



Common collector

Common emitter

Common base

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

7. Voltage divider biasing can also be used with common base and common collector circuit configurations.

III. Amplifier troubleshooting

A. Signal analysis

1. Signal analysis is used to isolate the failure to the defective stage in an amplifier system. In some cases, signal analysis can lead the technician to the faulty component.

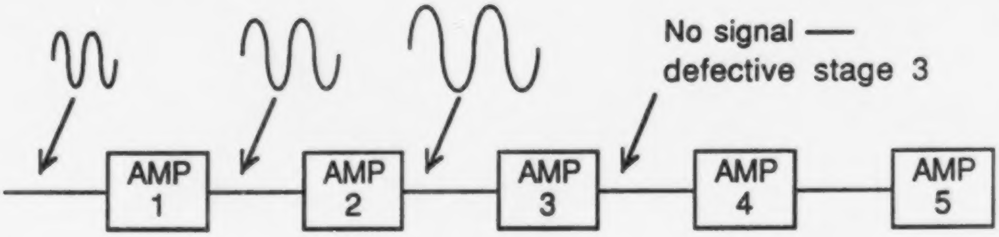
2. A technician can use the following test equipment.

   a. Oscilloscope (most widely used)

   b. Signal injector

   c. Signal tracer

3. The 'scope is used as an eye into the circuit to see where the signal chain is broken.



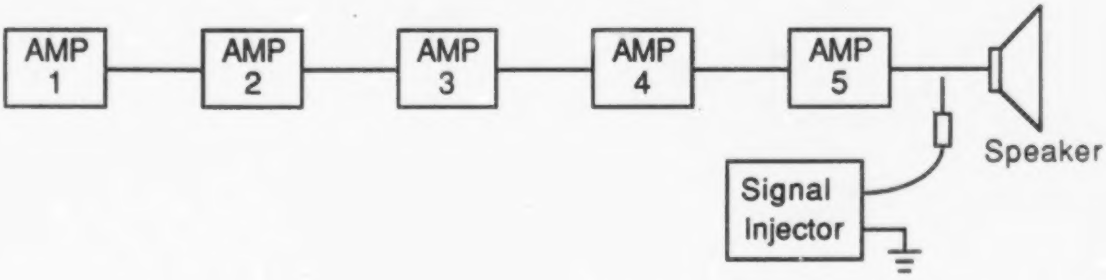
4. The key to using the oscilloscope is knowing what the signal is supposed to look like.

5. A signal tracer (simply an audio amplifier) can be used to isolate the defective stage in audio systems.

6. Instead of using the oscilloscope to locate where the fault is, the technician uses a signal tracer to hear where the signal is present and where it is not.

7. Audio signal injectors can inject audible tones to locate the faulty stage.

8. When no signal is heard from the speaker, the faulty stage is located by injecting at the output and working towards the input.



9. If the signal is heard when injected at the input of the speaker, then the speaker is good. If the signal is heard when injected at the input of stage 5, stage 5 is operational. If no signal is heard when injecting at the input of stage 4, then stage 4 must be faulty.

10. Video, chroma (color), synchronous and pulse injectors are also available.

B. Voltage analysis

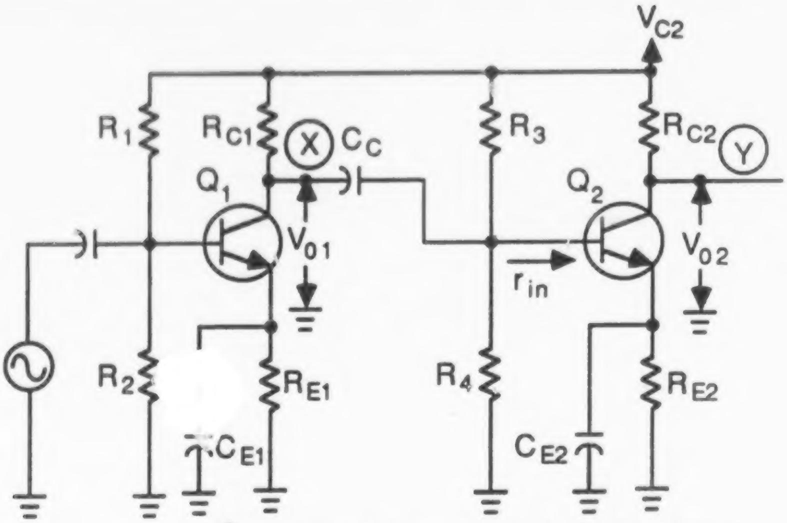
1. Once the technician has determined the faulty stage by using signal analysis, voltage analysis is used to help determine the faulty component.

2. Voltage measurements on the schematic are used as a reference to determine if the amplifier stage is operating properly.

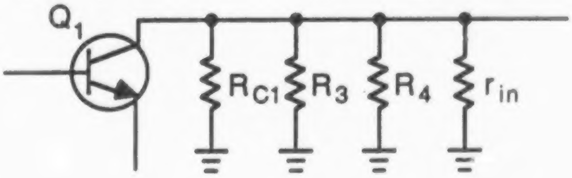
3. This figure shows a two-stage voltage divider, common emitter, capacitive-coupled amplifier.

4. If the E-B or B-C junction opens, there will be no current through the transistor. Therefore, R_{C1} will drop no voltage and the collector voltage of Q_1 will equal the source voltage.

Basic circuit



Equivalent coupling circuit between Q_1 and Q_2.



Credit: Oleksy, Jerome E. Electronic Troubleshooting. Indianapolis, IN: Bobbs-Merrill Educational Publishing, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

5. If R_{E1} opens, no current will flow through the transistor and collector voltage (V_C) equals source.

6. On a common emitter configuration, if the transistor is not conducting or is in cutoff mode of operation, the collector voltage will equal the source.

NOTE: Discuss the allowable tolerances on actual transistor measurements with the instructor.

7. If the transistor is conducting too much, the collector voltage (V_C) will be lower than the schematic-indicated value.

8. Collector voltage for a transistor in common emitter configuration will indicate if the transistor is in the cutoff, saturation or linear region of operation.

V_C	Comments
Too high	Transistor not conducting hard enough (near cutoff)
Too low	Transistor conducting too hard (near saturation)
Equal to source	Transistor not conducting (cutoff)

9. Voltage analysis is the process of measuring all bias voltages on the suspect stage, V_E, V_B and V_C to determine what component has failed.

10. Bias voltages can change due to transistors, resistors, capacitors, diodes, etc. that have opened, shorted or changed in value.

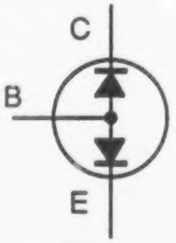
11. If the circuit failure is simply a loss of gain, suspect an open emitter-bypass capacitor.

12. If the circuit failure is poor low-frequency response, suspect a change in value of a coupling capacitor or emitter-bypass capacitor.

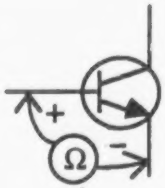
C. Component analysis

1. When the technician suspects a faulty component, the component must be tested for verification.
2. An ohmmeter is used to test many components.
3. In some cases, it may be best to use a component test (e.g., capacitor tester).
4. Transistors can be tested with a transistor tester or by ohmmeter.
5. To test a transistor with an ohmmeter, the two PN junctions must be tested.

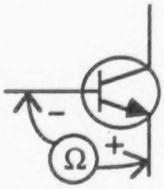
NOTE: The following procedure is for an NPN transistor. The same procedure can be used for a PNP.



NPN transistor



Low transistor



High transistor

Credit: Electronic Troubleshooting, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

6. A bipolar transistor consists essentially of two diodes back-to-back.
7. Place the negative ohmmeter lead on the emitter lead and the positive lead on the base lead.
8. This forward-biases the E-B junction; therefore, the meter should read a low resistance.
9. Reversing the leads will reverse-bias the junction, resulting in a high or infinite (ideal) resistance reading.
10. The same procedure is used to test the B-C junction.
11. If the meter measures 0Ω in both directions, the junction is shorted.
12. If the meter measures infinite ohms in both directions, the junction is shorted.
13. If the meter measures a constant resistance both ways, the junction is leaky.
14. To test an unknown transistor, alternately place the probes on the transistor until a forward-biased junction is found.
15. When a forward-biased junction is found, the negative lead must be connected to N-type material and the positive lead must be attached to P-type material.

16. One of these two leads must be the base.

17. The lead that is common to the third lead is the base.

18. At this point, a technician should be able to identify whether the transistor is NPN or PNP and which lead is the base. Emitter and collector leads cannot be found.

NOTE: Make sure the ohmmeter supplies sufficient voltage to forward-bias the junction.

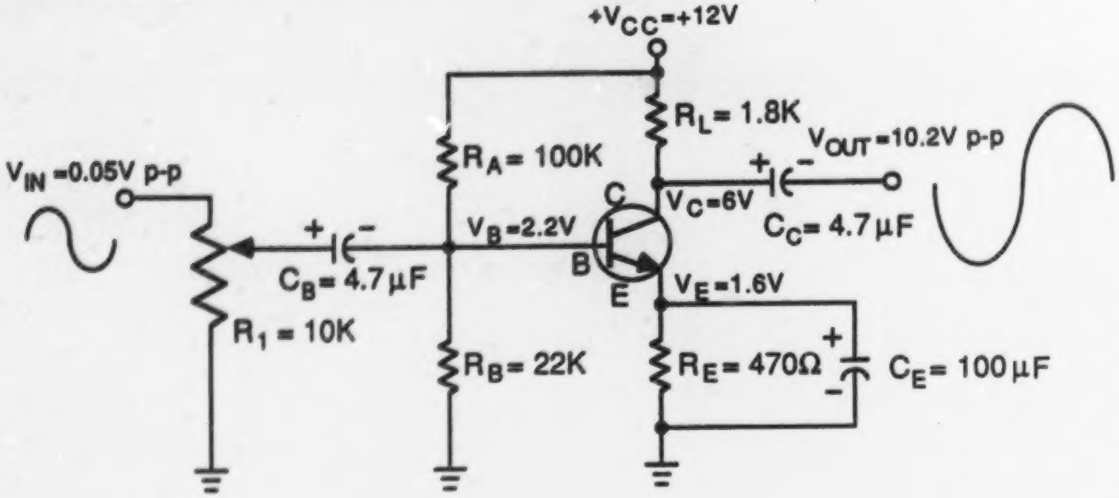
CAUTION: Some meters may have the batteries incorrectly installed.

D. Replacing transistors

1. Use a semiconductor replacement guide to select a suitable replacement transistor.
2. When replacing socketed transistors, cut leads on the replacement to the proper length.
3. Compare replacement transistor leads to the original to ensure proper biasing arrangement.
4. Do not repeatedly bend leads.
5. Test the replacement transistor before installing.
6. Do not overheat the replacement when installing. (Use heat sink.)
7. When the replacement is complete, measure bias voltages to ensure reliability.
8. Complementary push-pull transistors should be replaced in pairs.

BJT AMPLIFIERS

Using the schematic, explain the purpose of the following.


+V_{CC}=+12V
R_L= 1.8K
V_{OUT}=10.2V p-p
R_A= 100K
V_{IN}=0.05V p-p
+
−
C
V_C=6V
C_C= 4.7µF
V_B=2.2V
B
C_B= 4.7µF
E
V_E=1.6V
R_1 = 10K
R_B= 22K
R_E= 470Ω
C_E= 100µF

1. C_B

2. R_A

3. R_B

4. R_L

5. R_E

6. C_C

7. C_E

8. Q_1

9. R_1

10. If R_A opens, what would be the measurements on the following transistor leads?

a. V_E __________

b. V_B __________

c. V_C __________

11. If R_1 opens, what would the measurements on the following transistor leads be?

a. V_E __________

b. V_B __________

c. V_C __________

12. If R_E opens, what would the measurements on the following transistor leads be?

a. V_E __________

b. V_B __________

c. V_C __________

13. If R_A opens, what would be the measurements on the following transistor leads?

a. V_E __________

b. V_B __________

c. V_C __________

14. If C_B opens, what would be the measurements on the following transistor leads?

a. V_E __________

b. V_B __________

c. V_C __________

15. The transistor bias voltages measure as follows: $V_E = 0V$, $V_B = 0V$ and $V_C = 12V$. Is the transistor operating properly? (YES / NO) If not, what is most likely the failure and why?

16. The transistor bias voltages measure as follows: $V_E = 1.6V$, $V_B = 1.6V$ and $V_C = 12V$. Is the transistor operating properly? (YES / NO) If not, what is most likely the failure and why?

17. The transistor bias voltages measure as follows: $V_E = 1.6V$, $V_B = 2.2V$ and $V_C = 6V$. Is the transistor operating properly? (YES / NO) If not, what is most likely the failure and why?

18. The transistor bias voltages measure as follows: $V_E = 0V$, $V_B = 2.2V$ and $V_C = 12V$. Is the transistor operating properly? (YES / NO) If not, what is most likely the failure and why?

19. The transistor bias voltages measure as follows: V_E = 0V, V_B = .7V and V_C = 3V. Is the transistor operating properly? (YES / NO) If not, what is most likely the failure and why?

20. The transistor bias voltages measure as follows: V_E = 1.6V, V_B = 2.2V and V_C = 12V. Is the transistor operating properly? (YES / NO) If not, what is most likely the failure and why?

21. If all bias voltages measure fine but overall stage gain is noticeably low, what is the most likely cause?

22. What is the probable cause if the transistor stage is working properly except for a noticeable difference in low frequency response?

23. Does the circuit on this assignment sheet provide for temperature compensation? (YES / NO) If yes, how?

ANSWERS TO ASSIGNMENT SHEET

1. C_B = coupling capacitor; allows AC signal to pass; prevents R_1 from changing DC bias on base of Q_1

2. R_A = used in conjunction with R_B to form voltage divider network to bias the base of Q_1

3. R_B = used in conjunction with R_A to form voltage divider network to bias the base of Q_1

4. R_L = resistive load used to set V_C of Q_1 and develop output signal

5. R_E = emitter resistor used to determine emitter current and bias the V_E lead of Q_1; also introduces negative feedback for thermal stability

6. C_C = coupling capacitor passes the AC signal while blocking DC bias

7. C_E = emitter bypass capacitor provides a low reactance path for the AC signal to pass to increase overall stage gain.

8. Q_1 = transistor that when properly biased will provide power gain

9. R_1 = voltage divider that determines amount of signal that passes to base of Q_1

10. 0V, 0V, 12V

11. 1.6V, 2.2V, 6V

12. 1.6V, 2.2V, 12V

13. Decreased, decreased, 12V

14. 1.6V, 2.2V, 6V

15. No. R_A because there is no base bias

16. No. E_B short because V_E and V_B are equal

17. Yes. Transistor is conducting but is the AC signal passing? Does Q_1 have gain?

18. No. R_E open because there is no current path to drop voltage across R_E

19. No. C_E short because V_E is at ground potential

20. No. R_E open because there is no current through Q_1, the only cause for resulting voltages

21. C_E

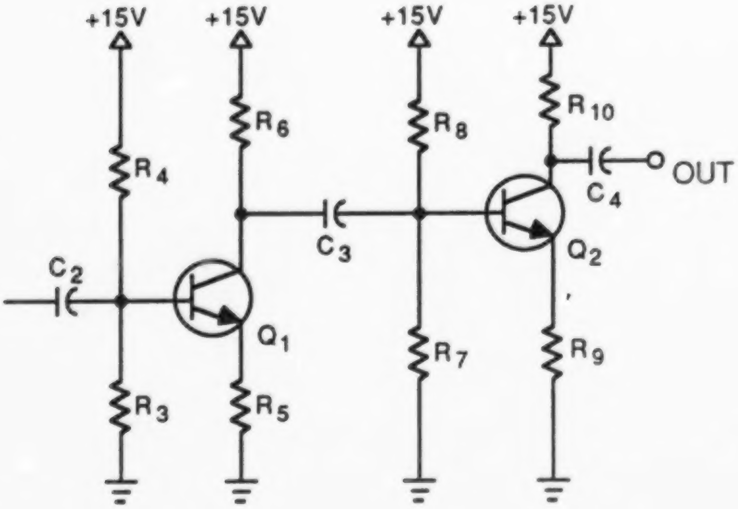
22. C_B

23. Yes. Through R_E

JS 1.1

TEST AND REPAIR BI-POLAR AMPLIFIER

Equipment:



15V power supply
Breadboard or proto-board

Resistors:	R_1 = 1K, R_2 = 2.2K, R_3 = 30K, R_4 = 120K, R_5 = 200, R_6 and R_{10} = 390, R_7 = 33K, R_8 = 116K, R_9 = 150
Capacitors:	C_1 = 47µF, C_2 = 10µF, C_3 and C_4 = 4.7µF
Voltages:	Q_1 E = 2V, B = 2.65V, C = 11.17V Q_2 E = 3.12V, B = 3.82V, C = 6.72V IC_1 V+ = +15V, V- = -15V

Procedure:		Evaluation 3	2	1	N
1.	Build the circuit as shown.	__	__	__	__
2.	Check signals and voltages for proper operation.	__	__	__	__
3.	If the input signal to IC_1 is .5Vp-p, what p-p voltage will the output signal be?	__	__	__	__
4.	Will the signal on the collector of Q_2 be in- or out-of-phase with the input of IC_1?	__	__	__	__
5.	What is the purpose of C_2?	__	__	__	__

6. Calculate the approximate gain of Q_1, then measure the input and output signals to verify calculations. — — — —

7. What will the base voltage be on Q_2 if R_{10} were to open? __________ — — — —

8. Lift one lead of R_{10} and measure the base voltage of Q_2; record the measured voltage. __________ If R_2 were to open, what would happen to the output of Q_2? — — — —

9. What will happen to the voltage at the base of Q_1 if R_3 were to open? — — — —

10. Lift the lead of R_3. Record the voltage measured at the base of Q_1. __________ Is it high or low? — — — —

11. Measure the voltages at the emitter and collector of Q_1. __________ , __________ Are they high or low? — — — —

12. Reinstall R_3, making sure that voltages are normal. — — — —

13. What would happen to the output of IC_1 if the negative voltage on the I.C. were lost? — — — —

14. Disconnect the negative voltage from IC_1. What happens to the output of the I.C.? — — — —

What is the purpose of C_4 in the circuit?

15. If R_7 were to open, what would happen to the voltage on the collector of Q_1? — — — —

On the collector of Q_2?

16. Lift a lead on R_7 and measure the bias voltages on Q_1 and Q_2. Why isn't the base voltage of Q_2 affected? — — — —

17. Calculate the total circuit gain; record this computation. Measure the input and output signal of the circuit. Calculate the gain and compare findings to the original calculation. — — — —

18. Lift a lead on R_5; measure the bias voltage on the collector of Q_1. Is it high or low? __________ — — — —

19. What should the voltage be on the emitter of Q_1? _________ Measure the voltage on the emitter. Why isn't the measured voltage the same as the calculation? — — — —

Average of above evaluations* — — — —

*This average is the student's final evaluation for competency E4: Test and repair bi-polar amplifier.

JS 1.2

IDENTIFY AND REPLACE SEMICONDUCTOR(S) ON A CIRCUIT BOARD

Equipment:

Old printed circuit board (preferably double-sided with several semiconductors)
Substitution guide

Procedure:	Evaluation 3	 2	 1	 N
1. Remove semiconductor(s) identified by instructor.	___	___	___	___
2. Using substitution guide, find appropriate replacement semiconductor(s) for components removed.	___	___	___	___
3. Re-install parts provided by instructor.	___	___	___	___
Average of above evaluations*	___	___	___	___

*This average is the student's final evaluation for competencies D16 and D17.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XIV: SERVICING BJT AMPLIFIERS

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which would not be used for signal analysis?

- a. Multimeter
- b. Oscilloscope
- c. Signal injector
- d. Signal tracer
- e. Function generator

____ 2. If a meter placed across a BJT junction measures 0Ω both ways, which describes the junction?

- a. Open
- b. Shorted
- c. Leaky
- d. Good
- e. Intermittent

____ 3. If a meter placed across a BJT junction measures infinite ohms both ways, which describes the junction?

- a. Open
- b. Shorted
- c. Leaky
- d. Good
- e. Intermittent

____ 4. If a meter placed across a BJT junction measures 2000Ω both ways, which describes the junction?

- a. Open
- b. Shorted
- c. Leaky
- d. Good
- e. Intermittent

____ 5. If a meter placed across a BJT junction measures low ohms one way and infinite ohms the other way, which describes the junction?

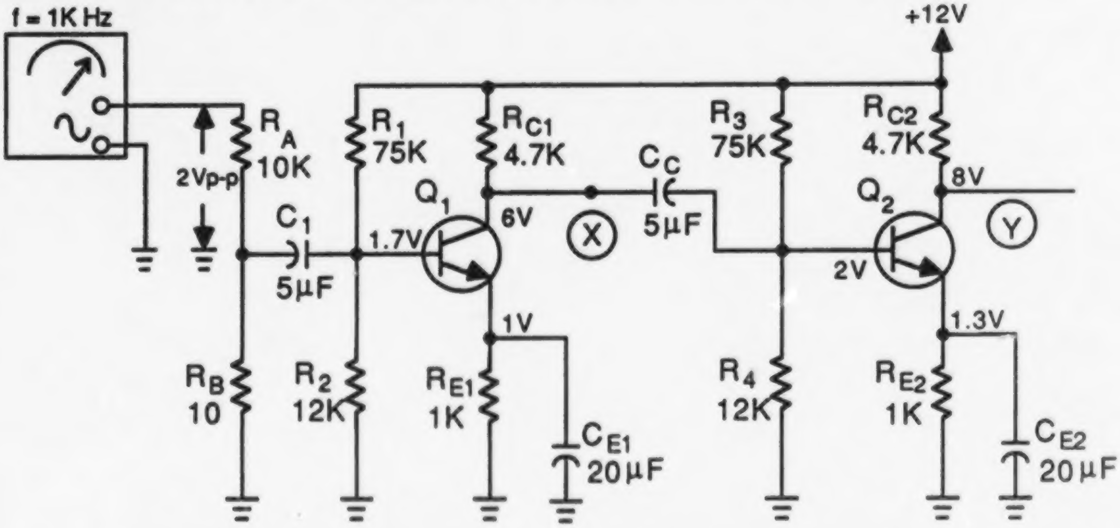
- a. Open
- b. Shorted
- c. Leaky
- d. Intermittent
- e. Good

Select "a" for true statements and "b" for false ones.

____ 6. A properly operating amplifier circuit will read 0.6-0.7V between emitter and base.

____ 7. Voltage analysis can often locate the faulty component.

For questions 24-29, refer to the figure below. More than one answer may be correct.



f = 1K Hz
+12V
R_A 10K
2Vp-p
C_1 5µF
R_1 75K
R_{C1} 4.7K
Q_1
1.7V
6V
X
C_C 5µF
R_3 75K
R_{C2} 4.7K
8V
Q_2
Y
2V
1V
1.3V
R_B 10
R_2 12K
R_{E1} 1K
C_{E1} 20µF
R_4 12K
R_{E2} 1K
C_{E2} 20µF

Credit: Electronic Troubleshooting, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

____ 8. Suppose the collector of Q_1 measures 12V. Which would you suspect?

- a. Open transistor junction
- b. Shorted transistor
- c. R_1 open
- d. RC_1 open
- e. Open emitter resistor

____ 9. If the collector of Q_1 measures 12V and the base voltage measures 0V, which component is faulty?

- a. Open transistor junction
- b. Shorted transistor
- c. R_1 open
- d. RC_1 open
- e. Open emitter resistor

____ 10. If the collector of Q_1 measures 0V, which of the following could be faulty?

- a. Open transistor junction
- b. Shorted transistor
- c. R_1 open
- d. RC_1 open
- e. Open emitter resistor

___ 11. If the collector of Q_1 measures much lower than normal, which of the following could be faulty?

a. Open transistor junction
b. Shorted transistor
c. R_1 open
d. RC_1 open
e. Open emitter resistor

___ 12. The amplifier has a noticeable decrease in gain. As you measure all bias voltages on Q_1 and Q_2, you find they are all good. What is the problem?

a. Open transistor junction
b. Shorted transistor
c. R_2 open
d. CE_1 open
e. Open emitter resistor

___ 13. When using signal analysis to troubleshoot the amplifier, you notice signal is present at the collector of Q_1 but is not at the base of Q_2. What is most likely the failure?

a. Open Q_1
b. Open Q_2
c. Open C_C
d. Open C_{E1}
e. Shorted C_{E1}

ANSWERS TO UNIT TEST (E4)

1. a
2. b
3. a
4. c
5. e
6. a
7. a
8. a, c, e
9. c
10. d
11. b, d
12. d
13. c

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XV: SERVICING FET AMPLIFIERS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to demonstrate the proper procedure for troubleshooting multistage FET amplifiers. Competencies will be demonstrated by completing the assignments and achieving the specified score on the unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Identify terms and definitions related to multistage FETs. (competency E2)

1.2 List the different types of FETs (unijunction devices). (competencies D5-8, E2)

1.3 Describe the operation of a FET amplifier. (competency D5-6, E2)

1.4 List techniques used to bias FETs.

1.5 Identify FET amplifier circuit configurations and troubleshooting techniques.

1.6 Using multimeter analysis techniques, identify the faulty component on a FET amplifier stage. (competency E5)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XV: SERVICING FET AMPLIFIERS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

  1. Lesson 1: FET SERVICING

    a. Information outline

    b. Transparency master

      TM 1.1: Depletion regions

    c. Assignment sheet

      AS 1.1: Schematic interpretation

    d. Answers to assignment sheet

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Semiconductor Devices. Benton Harbor, MI: Heath Co., 1975.

2. Leonard, Vincient F., Jr. Transistor Circuit Design. Heathkit Continuing Education. Benton Harbor, MI: Heath Co., 1983.

3. Oleksy, Jerome E. Electronic Troubleshooting. Indianapolis, IN: Bobbs-Merrill Educational Publishing, 1983.

4. Schuler, Charles A. Electronics: Principles and Applications. 2nd ed. St. Louis: McGraw-Hill, 1984.

NOTES TO THE INSTRUCTOR

A. Suggested supplemental materials

1. "Please . . . Don't Give Me Any Static." (videotape) St. Louis: McDonnell Douglas Corp., 1985. (Available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

2. JFET Amplifiers (E-87-331, video). Sedalia, MO: The Media Center, State Fair Community College, 1987. (Available for purchase from SFCC; available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

MODULE: SEMICONDUCTOR DEVICES

UNIT XV: SERVICING FET AMPLIFIERS

LESSON 1: FET SERVICING

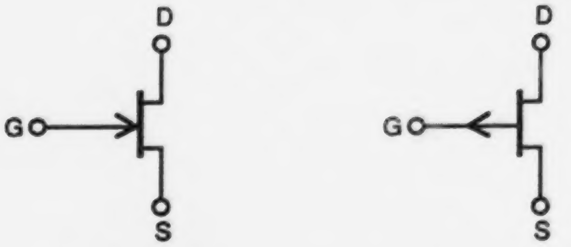
I. Terms and definitions

- A. Continuity--a continuous path from one point to another
- B. Depletion region--area void of any majority carriers. A depletion mode device uses the depletion region to control the resistance of the device, thereby controlling current through the device.
- C. Enhancement mode--Enhancement mode devices do not have a channel from source to drain; therefore, they do not conduct until the application of the proper gate voltage creates a channel.
- D. FET (field-effect transistor)--P-channel or N-channel transistor that is controlled by voltage, not current
- E. Forward bias--application of positive voltage to P-type material and negative voltage to N-type material. Forward bias results in a low resistance that helps current flow.
- F. Impedance--the total opposition to current in an AC circuit; a combination of circuit resistances and reactance
- G. Linearity--characteristic where the output signal is directly proportional to the input signal
- H. Reverse bias--application of negative voltage to P-type material and positive voltage to N-type material. It results in a high resistance in the semiconductor and allows no current flow.
- I. Signal analysis--using an oscilloscope, signal tracer/injector or other device to isolate the break in the signal chain

II. Types of FETs (unijunction devices)

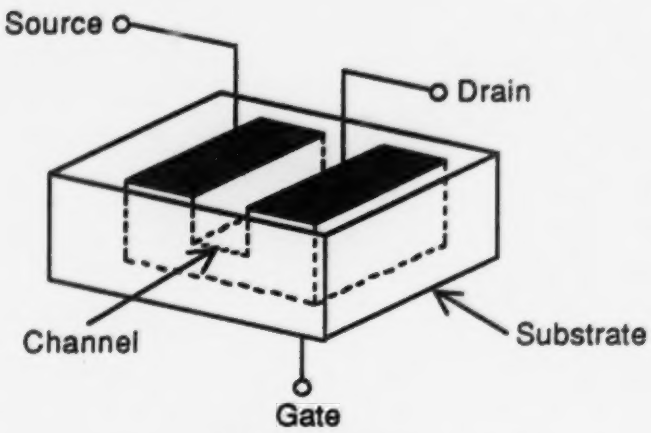
- A. JFET (junction field effect transistor)
  - 1. The reason it is called a JFET is because of the junction between the gate and the source-drain channel.
  - 2. FET devices offer some advantages over BJTs.
    - a. FETs have extremely high input impedance.
    - b. FETs have low noise output. (These two characteristics make FETs desireable for pre-amps where input impedance must be high and noise low.)
    - c. A FET is a voltage-controlled amplifier.
    - d. FETs have better linearity.
    - e. FETs are good RF amplifiers.
  - 3. There are two types of JFETs.
    - a. N-channel JFET

        - b. P-channel JFET
    - 4. The leads on the JFET are labeled S, D and G.
        - a. Source leads (S) can be compared to BJT emitters.
        - b. The drain lead (D) is like the collector on a BJT.
        - c. The gate lead (GS) can be compared to the base on a BJT.
- B. MOSFETs (metal oxide field-effect transistor)
    - 1. A MOSFET is sometimes referred to as the IGFET, which is the acronym for insulated gate field effect transistor.
    - 2. The gate is insulated from the source/drain channel.
    - 3. There are two different varieties of MOSFETs.
        - a. Depletion mode MOSFET



N - channel P - channel

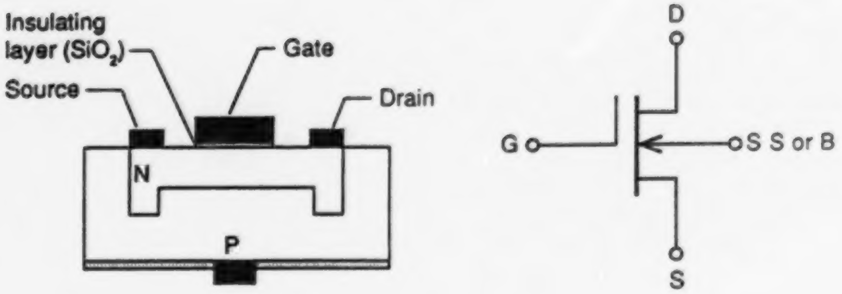
JFET schematic symbols



JFET construction

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

        - b. Enhancement mode MOSFET
    - 4. Depletion mode MOSFETs can be one of two types.
        - a. N-channel depletion mode MOSFET


Insulating layer (SiO_2)
Gate
Source
Drain
N
P
D
G
S S or B
S

N-channel depletion-mode MOSFET construction and schematic

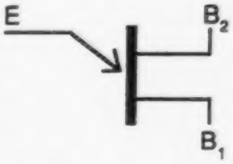
b. P-channel depletion mode MOSFET

5. Enhancement mode MOSFETs can be one of the following.

   a. N-channel enhancement mode MOSFET

   b. P-channel enhancement mode MOSFET

C. UJT (unijunction transistor)



1. Three-terminal semiconductor used as a switching device in oscillators and circuits

2. Has one PN junction (two leads connected to the N material and one lead connected to the P material)

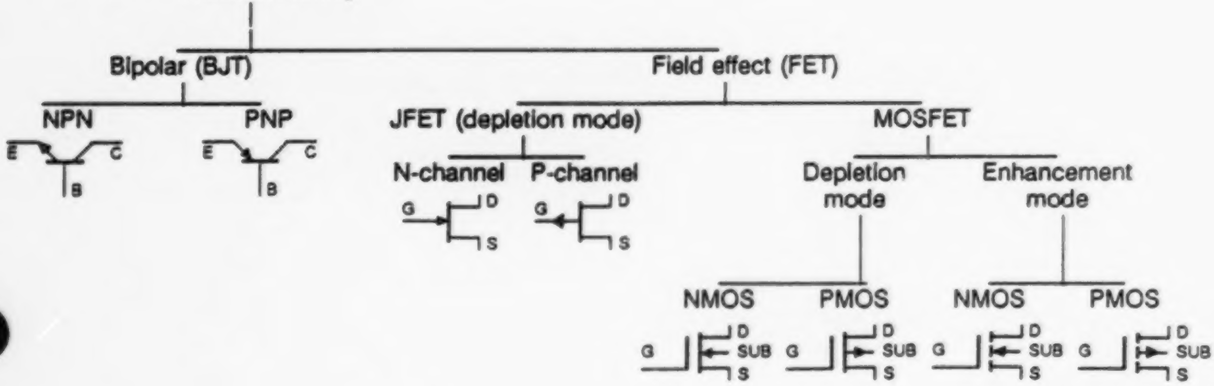
3. Has a firing point controlled by a fixed voltage ratio inside the component (called intrinsic stand-off ratio)

D. PUT (programmable unijunction transistor)

1. Switching device where voltage ratio that controls the firing point is controllable (programmable)

2. Also used in oscillating circuits, like the UJT

E. Transistor family


Bipolar (BJT)
Field effect (FET)
NPN
PNP
E
C
B
E
C
B
JFET (depletion mode)
MOSFET
N-channel
P-channel
G
D
S
G
D
S
Depletion mode
Enhancement mode
NMOS
PMOS
NMOS
PMOS
G
D
SUB
S
G
D
SUB
S
G
D
SUB
S
G
D
SUB
S

III. FET operation (TM 1.1)

A. JFET operation

1. A review of Unit IX may be necessary to better understand FET amplifier servicing.
2. Remember, the gate lead serves as the control device that determines the amount of current flow that exists from source to drain (I_{DS}).
3. As the reverse bias applied to the gate and channel increases, channel resistance increases, resulting in a decrease in source-to-drain current (I_{DS}).
4. As the reverse bias applied to the gate and channel decrease, channel resistance decreases, resulting in an increase in I_{DS}.
5. On a JFET, the gate-to-source voltage must never be forward biased as this would cause current to flow from source to gate.
6. The source-to-gate junction behaves like any forward-bias PN and junction. There is no longer current from source to drain.

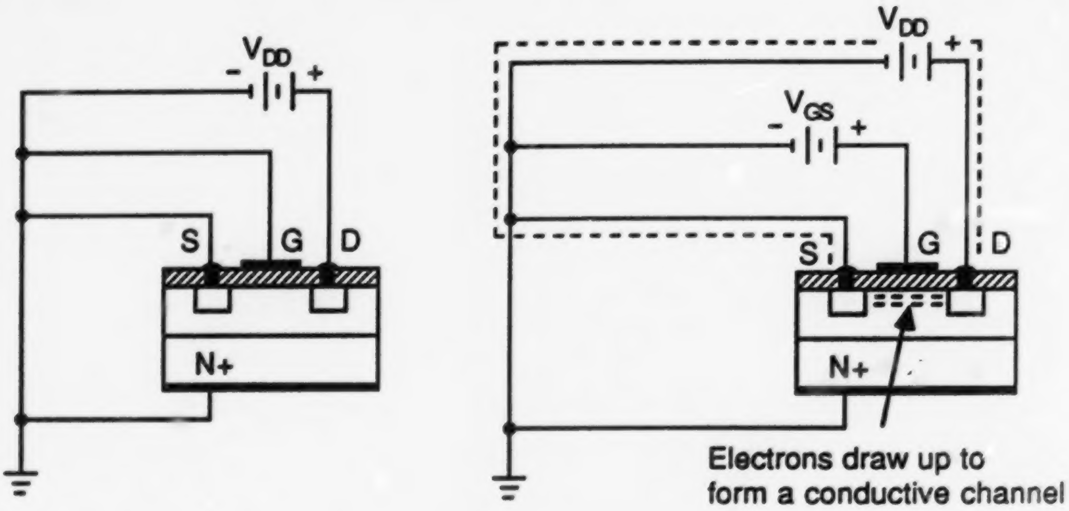
B. Depletion mode MOSFET

1. The depletion mode MOSFET operates identically to the JFET.
2. Since the gate lead is isolated from the base or substrate material, forward bias can exist on the gate to source leads.
3. If a forward-bias voltage exists between the source to gate junction, there is no depletion region within the channel; therefore, current is maximum.

NOTE: Remember to observe static handling precautions when working with any MOSFET.

C. Enhancement mode MOSFET

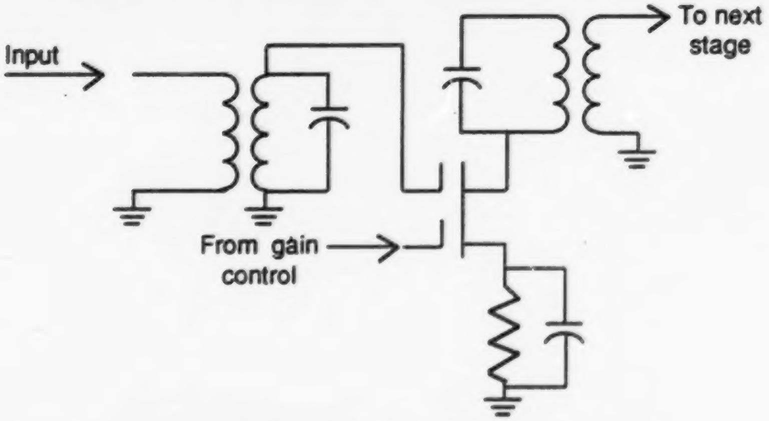
1. The enhancement mode MOSFET has no complete channel from source to gate.
2. Since there is no complete channel, the transistor must be "enhanced" to conduct. This is done by applying a forward-biased gate voltage to allow majority carriers to gather under the gate lead.
3. This creates a channel between the source and gate leads, causing the transistor to conduct.
4. The more forward bias that is applied to the gate, the more majority carriers are attracted, and the greater the current from source to drain (I_{DS}).


V_DD
- +
S
G
D
N+
V_DD
V_GS
- +
S
G
D
N+
Electrons draw up to
form a conductive channel

Credit: Oleksy, Jerome E. Electronic Troubleshooting. Indianapolis, IN: Bobbs-Merrill Educational Publishing, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

MOSFET current flow

5. Where depletion mode devices are normally on when no bias is applied to the gate, enhancement mode devices are normally off and a proper bias voltage must be applied to the gate to cause the transistor to conduct.


Input
To next
stage
From gain
control

Dual gate MOSFET for automatic gain control

6. Some MOSFETs have dual gates which allow one gate to conduct while the other is used as the control device.

IV. FET amplifiers

A. Biasing techniques

1. FET amplifiers must be properly biased to operate.

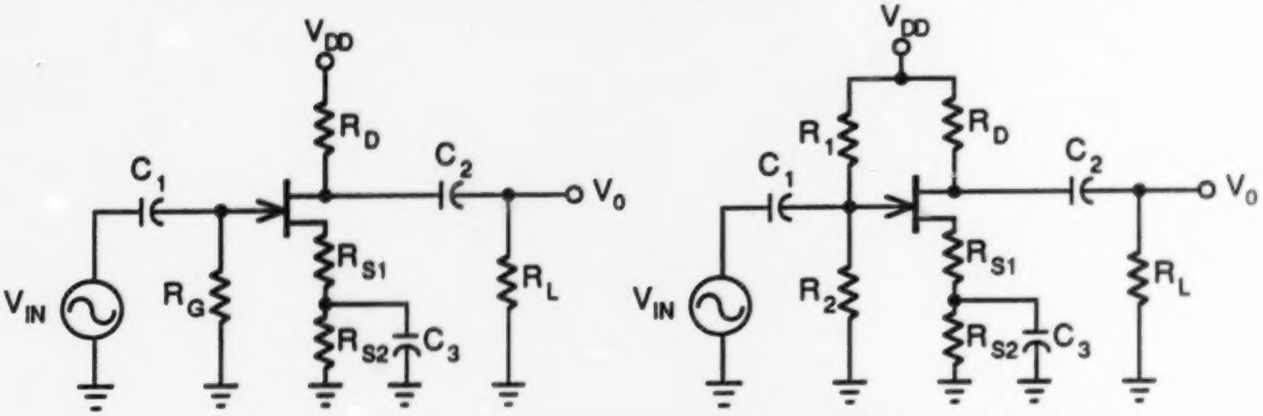
2. Two basic biasing techniques are used.

a. Source or self bias

b. Combination or voltage-divider bias

B. Circuit configurations

1. Common source (most widely used; comparable to BJT common emitter)

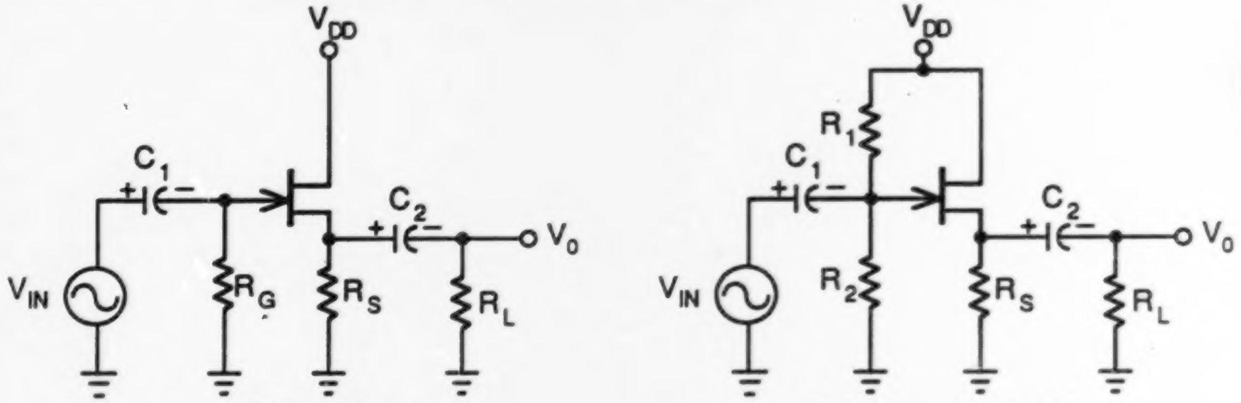


Self bias

Voltage – divider bias

Common source

2. Common drain (comparable to BJT common collector or emitter follower)



Self – bias

Voltage – divider bias

Common drain

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

NOTE: Common drain is also referred to as source follower.

C. FET amplifiers

1. As with all amplifiers, the JFET must be properly biased to amplify the input signal (V_s).

2. The input signal (V_s) is applied to the gate of the JFET through coupling capacitor C_C.

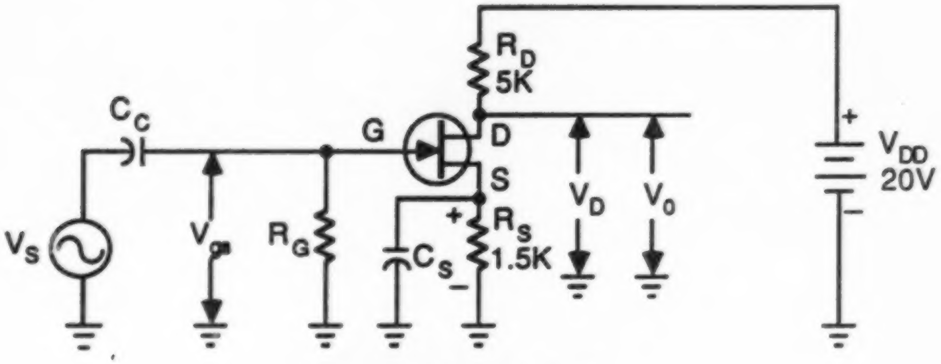
3. Resistor R_G holds the gate above ground potential and allows the input signal to be coupled to the gate through capacitor C_C.

4. The source is connected to ground through resistor R_S.

5. The drain is connected to a positive supply voltage (V_{DD}) through resistor R_D.

6. With 0V gate voltage, resistor R_D, R_S and the internal resistance of the source-to-drain channel determine source-to-drain current (I_{DS}).

$$I_{DS} = V_{DD} / R_D + R_S + R_{SD}$$



JFET small-signal amplifier

Credit: Electronic Troubleshooting, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

7. With a V_{GS} of 0 volts, assume that source-to-drain current (I_{DS}) is 2 mA.

8. Using Ohm's Law, the drain bias voltage V_D and source bias voltage can be calculated. Subtract the voltage drop across R_D (E_{RD}) from the supply voltage.

$$E_{RD} = 2 \text{ mA} \times 5K\Omega = 10V$$

$$V_D = 20V\ (V_{DD}) - 10V\ (E_{RD}) = 10V$$

9. To calculate source voltage, (V_S) multiply source to drain current times R_S.

$$E_{RS} = 2 \text{ mA} \times 1.5K\Omega = 3V$$

10. R_D and R_S are used to bias the drain and source.

NOTE: Remember, all of these calculations take place with no gate voltage ($V_{GS} = 0V$)

11. When a signal is applied to the gate, it will produce a charge in current from source to drain.

12. As the signal goes more negative, the depletion region within the channel increases and source (I) to drain (I_{DS}) current decreases.

13. This causes a decrease in voltage drop across R_D (E_{RD}), which results in an increase in drain voltage V_D.

14. When the signal goes more positive, the depletion region within the channel decreases and source-to-drain current increases (I_{DS}).

15. This causes an voltage drop increase across R_D (E_{RD}), which results in a decreased V_D.

16. The output signal is present from the drain lead (V_D) to ground.

17. The output signal (V_D) is 180° out of phase with the input (V_S).

18. When the input is applied to the gate and output taken from the drain, the circuit is in the common source configuration.

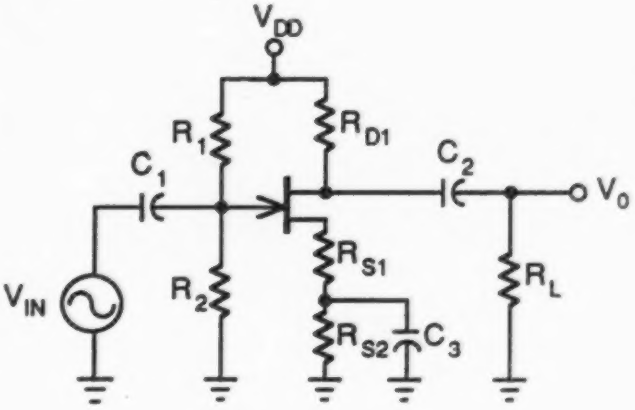
19. The common-source circuit pictured earlier uses source bias.

20. Capacitor C_S is used to keep the source at ground potential B with respect to the AC signal.

D. Common source, combination bias

1. A voltage divider used to bias the gate lead creates combination bias, which is sometimes referred to as voltage divider bias.

2. Using Ohm's Law, the voltage divider can be designed to set the gate to any desired voltage.



Voltage divider bias

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

3. The operation is identical to common source bias.

E. Common drain configuration

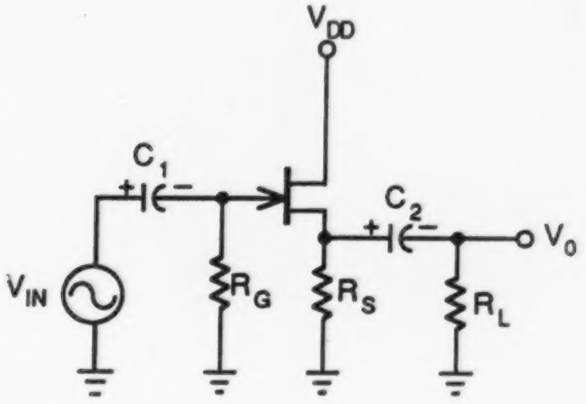
1. The common drain FET amplifier is the counterpart of the bipolar common collector or emitter follower circuit.

2. The common drain configuration can be referred to a source follower since the input and output are in phase.

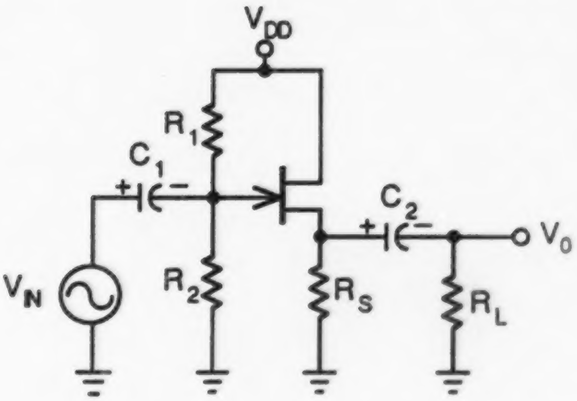
3. An illustration of an N-channel self-biased common drain amplifier follows.

4. As the N-type gate goes more positive, source-to-drain current (I_{DS}) increases, resulting in a larger voltage drop across R_S.

5. The following illustration shows a voltage divider biased, common drain configuration. Its operation is identical to the previous circuit.



Self-bias



Voltage divider bias

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

V. Troubleshooting FET amplifiers

A. Signal analysis to isolate stage of problem

1. The bias voltages indicated on the JFET small-signal amplifier schematic diagram on pg. 418 are when the transistor is operating under normal operating conditions with no component failures.
2. If the source-drain channel opens, no source-to-drain current (I_{DS}) will exist.
3. This results in a loss of current through R_D.
4. If there is no current through R_D, the voltage drop across R_D (E_{RD}) is zero. Therefore, drain voltage (E_D) is equal to supply voltage.
5. The source resistor (R_S) will also drop 0V since there is no current present here, either.
6. This results in a source voltage (E_{RS}) of 0V.

6. This results in a source voltage (E_{RS}) of 0V.

B. Voltage analysis to determine faulty component

1. After signal analysis determines the faulty stage, the technician can use voltage analysis of the **drain, gate and source leads** to determine the faulty component.

2. Drain voltage will determine if the transistor is conducting or not.

3. If the drain voltage is equal to the supply voltage, the transistor is not conducting.

4. If R_S opens, no current is present through the channel, causing drain voltage to equal supply voltage.

5. However, when the technician places the meter from source to ground to measure source voltage (V_S), the meter will complete the path from ground to source, causing a voltage greater than 0V to be measured here. This may lead the technician to believe R_S was good, when it is in fact faulty.

6. If R_D opens, there is no supply voltage at the drain lead. The transistor would not conduct. Drain voltage (V_D) and source voltage (V_S) would measure 0V.

7. If C_S shorts, resistance from source to ground decreases to 0Ω, causing an increase in current through the transistor.

8. This causes an increase in voltage drop across R_D, resulting in a drop in drain voltage (V_D).

9. The transistor would conduct too hard, causing severe distortion or complete loss of signal.

NOTE: C_S is a source bypass capacitor used in the same manner as emitter bypass capacitors in BJT amplifiers (to increase gain).

10. When a FET's drain voltage (V_D) is low, the FET is conducting too hard.

11. A high drain voltage (V_D) is an indication that the FET is not conducting hard enough. This can be caused by a bias resistor changing value or a defective transistor.

12. Of course, if the drain voltage (V_D) equals supply voltage, the transistor is in the cut-off mode of operation. This also can be caused by a faulty bias resistor or FET.

13. In most cases, the amplifier is biased for class A operation, so the technician should expect to see drain voltages that are approximately one-half of supply voltage.

VI. Testing FETs

A. JFETs (N-channel or P-channel)

1. Check the channel for continuity.

2. Test the gate-to-source PN junction like any PN junction diode.

3. Test the gate-to-drain PN junction like any PN junction diode.

4. Remember, the JFET has no insulated gate since it is not a MOSFET; therefore, static precautions are not necessary.

B. Depletion mode and enhancement mode MOSFETs

1. Observe static precautions.
2. Test the channel for continuity.
3. Since the gate is insulated from the source and drain, gate-to-source and gate-to-drain may not be tested.
4. Some manufacturers recommend testing by substitution if the technician suspects a faulty MOSFET.

NOTE: If necessary, a simple test circuit can be built to determine if the gate is controlling the source to drain current.

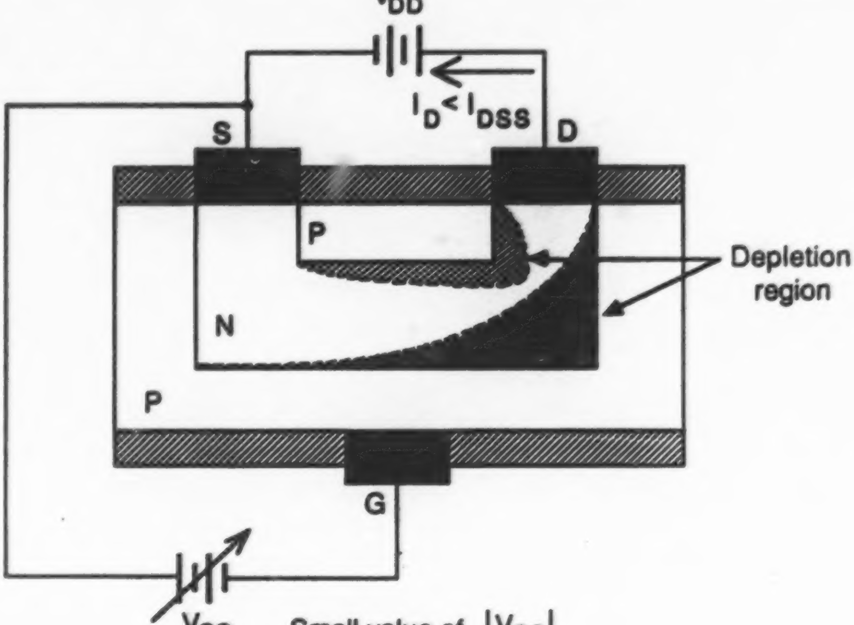
C. MOSFET selection and installation

1. Use a semiconductor cross-reference guide to select a replacement MOSFET.
2. Test MOSFETs before installation.
3. Cut leads to appropriate length before installation.
4. Ensure that the replacement FET transistor has the same biasing arrangement as the original.
5. Avoid excessive heat when soldering in the replacement.

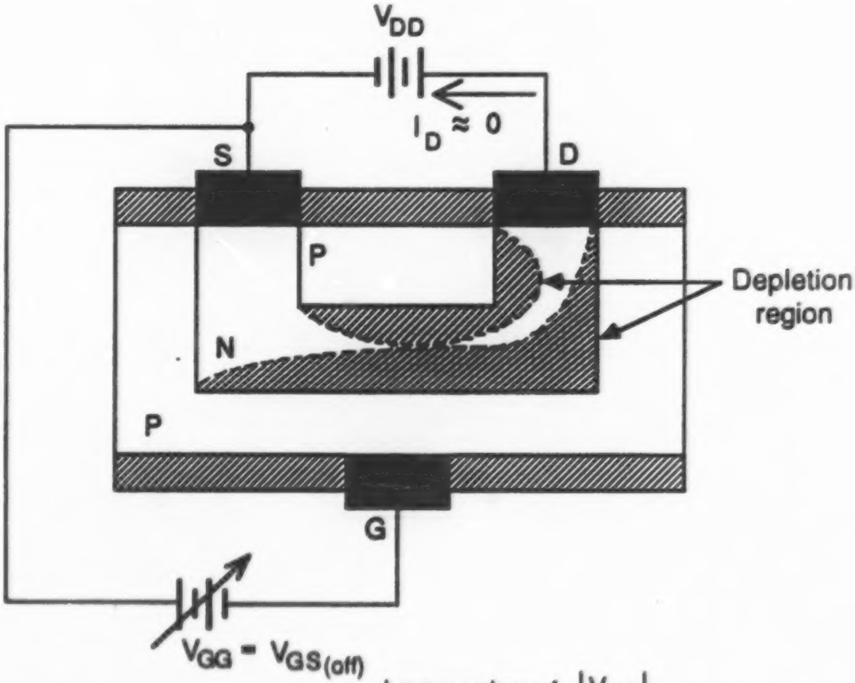
D. MOSFET replacement

1. Prior to mounting, keep all leads shorted together or use conductive foam.
2. Use an approved grounding strap to keep your body free from static electricity.
3. Use a grounded soldering iron.
4. Always keep power off when inserting or installing any replacement device.

DEPLETION REGIONS


V_{DD}
$I_D < I_{DSS}$
S
D
P
N
P
G
Depletion region
V_{GG}

Small value of $|V_{GG}|$

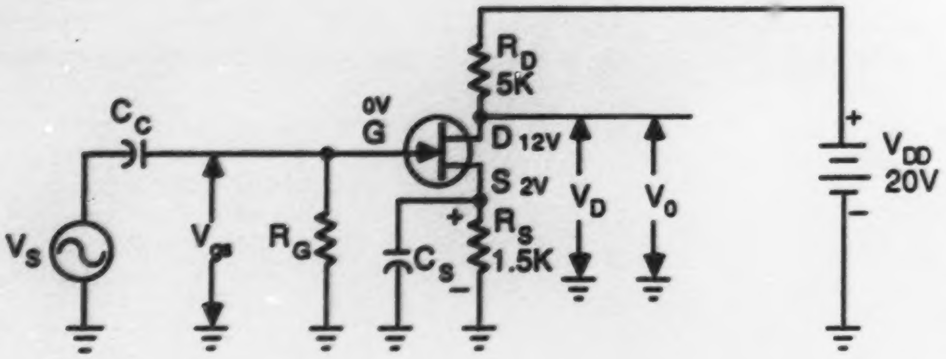

V_{DD}
$I_D \approx 0$
S
D
P
N
P
G
Depletion region
$V_{GG} = V_{GS(off)}$

Large value of $|V_{GG}|$

Credit: Courtesy of Heathkit Educational Systems, Benton Harbor, Mich.

SCHEMATIC INTERPRETATION

Using the illustration of a JFET small-signal amplifier, explain the purpose of the following.


C_C
0V
G
R_D
5K
D 12V
S 2V
V_S
V_gs
R_G
C_S
+
R_S
1.5K
−
V_D
V_0
+
−
V_DD
20V

Credit: Electronic Troubleshooting, 1963. Used by permission of Glencoe/McGraw-Hill Educational Division.

1. C_1
2. R_1
3. R_{S1-2}
4. R_{D1}
5. C_S
6. FET
7. If R_S opens, what would be the measurements on the following transistor leads?

V_G ______

V_S ______

V_D ______

8. If R_D opens, what would be the measurements on the following transistor leads?

V_S ______

V_D ______

V_G ______

9. If R_G opens, what would be the measurements on the following transistor leads?

V_G ______

V_S ______

V_D ______

10. If C_C opens, what would be the measurements on the following transistor leads?

V_G ______

V_S ______

V_D ______

11. The transistor bias voltages measure as follows: $V_S = 0V$, $V_G = 0V$ and $V_D = 20V$. Is the transistor operating properly? __________ If not, what is most likely the failure and why?

12. What is most likely the cause if all bias voltages measure fine but the overall stage gain is noticeably low?

13. If the transistor stage is working properly except for a noticeable difference in low frequency response, what problem would you suspect?

14. Does this circuit provide for temperature compensation? If yes, how?

ANSWERS TO AS 1.1

1. Coupling capacitor; couples the signal from FET input to gate
2. Biases the JFET gate to decrease the channel size
3. Biases the source of JFET above-ground potential; also provides source feedback
4. Biases the drain of JFET; serves as voltage divider
5. Source bypass capacitor; increases the gain of the stage by reducing degenerative feedback
6. Field-effect transistor; device used to provide gain
7. .4V, 0V, 12V
8. 0V, 0V, .4V
9. 0V, cannot be determined, cannot be determined
10. .4, 2, 8
11. No. R_{S1}, R_{S2} or R_D
12. C_3
13. C_1 or C_2
14. Yes. R_{S1} and R_5

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XV: SERVICING FET AMPLIFIERS

UNIT TEST

Select the option which answers the question or completes the statement. More than one answer may be correct.

____ 1. A FET amplifier can not be placed in which of the following circuit configurations?

a. Common gate
b. Common base
c. Common source
d. Common drain
e. Common channel

____ 2. Which of the following circuit configurations would be comparable to a common emitter configuration?

a. Common base
b. Common gate
c. Common collector
d. Common source
e. Common channel

____ 3. Which of the following circuit configurations is the most widely used?

a. Common gate
b. Common base
c. Common source
d. Common drain
e. Common channel

____ 4. Which of the following is not a type of FET?

a. N-channel JFET
b. P-channel JFET
c. N-channel depletion mode MOSFET
d. P-channel enhancement mode JFET
e. P-channel depletion mode MOSFET

Select "a" for true statements and "b" for false ones.

____ 5. If the gate voltage applied to an N-channel JFET is 0 volts, the drain current is minimum.

____ 6. A feedback path can be added to FET amplifiers to provide thermal stability.

____ 7. Circuit configurations from FET amplifiers have comparable characteristics to BJT amplifiers.

____ 8. If the gate voltage applied to an N-channel enhancement mode MOSFET is 0 volts, the drain current will be maximum.

____ 9. Depletion mode MOSFETs can be forward biased at the gate-source junction.

____ 10. Often times, voltage analysis can locate the faulty component.

Select the option which answers the question or completes the statement.

___ 11. Which is true of source bypass capacitors?

a. Provide no feedback
b. Increase the gain of the stage
c. Provide positive feedback
d. Provide thermal stability
e. Quasi-complementary push-pull output

___ 12. If a meter placed across a JFET channel measures infinite ohms both ways, what has happened to the junction?

a. Open
b. Shorted
c. Leaky
d. Good
e. Closed

___ 13. If a meter placed across a JFET junction measures 2000Ω both ways, what has happened the junction?

a. Open
b. Shorted
c. Leaky
d. Good
e. Closed

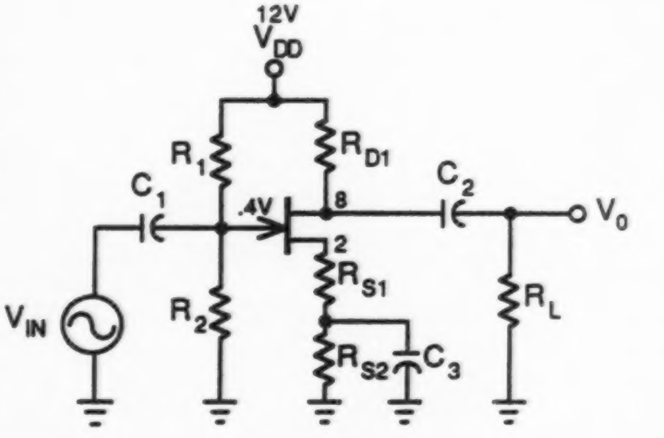
___ 14. If a meter placed across a JFET junction measure low ohms one way and infinite ohms the other way, which of the following would describe the junction?

a. Open
b. Shorted
c. Leaky
d. Good
e. Closed

For the next four questions, refer to this schematic. More than one answer may be correct.

___ 15. Suppose the drain of Q_1 measures 12 volts. Which of the following would you suspect?

a. Open channel junction
b. Shorted transistor
c. R_1 open
d. R_{D1} open
e. Open source resistor



Voltage divider bias

____ 16. If the drain of Q_1 measures 4V and the gate voltage measures 0V, which component could be faulty?

a. Open transistor channel
b. Shorted transistor
c. R_1 open
d. R_{D1} open
e. Open source resistor

____ 17. If the drain of Q_1 measures 0V, which of the following could be faulty?

a. Open transistor channel
b. Shorted transistor
c. R_1 open
d. R_{D1} open
e. Open source resistor

Match the following terms and definitions.

____ 18. Using an oscilloscope, signal tracer/injector or other device to isolate the break in the signal chain

____ 19. Application of positive voltage to P-type material and negative voltage to N-type material

____ 20. Characteristic where the output signal is directly proportional to the input signal

____ 21. Continuous path from one point to another

____ 22. P-channel or N-channel transistor that is controlled by voltage, not current

____ 23. Area void of any majority carriers

____ 24. Total opposition to current in an AC circuit; a combination of circuit resistances and reactance

____ 25. Switching device where voltage ratio that controls the firing point is programmable

____ 26. Three-terminal semiconductor used as a switching device in oscillators and circuits; has a firing point controlled by a fixed voltage ratio inside the component

a. Continuity
b. Depletion region
c. Enhancement mode
d. FET
e. Forward bias
ab. Impedance
ac. Linearity
ad. PUT
ae. Reverse bias
bc. Signal analysis
bd. UJT

ANSWERS TO UNIT TEST

1.	b, d, e	(E2)
2.	d	(E2)
3.	c	(E2)
4.	d	(E2)
5.	b	(E5)
6.	a	(E2)
7.	a	(E2)
8.	b	(E2)
9.	a	(E2)
10.	a	(E2)
11.	b	(E5)
12.	a	(E2)
13.	c	(E5)
14.	d	(E5)
15.	a, e	(E5)
16.	c	(E5)
17.	d	(E5)
18.	bc	(E2)
19.	e	(E2)
20.	ac	(E2)
21.	a	(E2)
22.	d	(E2)
23.	b	(E2)
24.	ab	(E2)
25.	ad	(D8)
26.	bd	(D7)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XVI: SERVICING OP AMP CIRCUITS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to demonstrate the proper procedure for troubleshooting circuits employing operational amplifiers (op amps). Competencies will be demonstrated by achieving the specified score on the unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Define terms and definitions.

1.2 Explain op amp construction and characteristics.

1.3 Identify the following op amp circuits: inverting and non-inverting amplifiers, comparators, mixers, waveshaping circuits, active filters and oscillators.

1.4 Test and repair operational amplifier. (competency E6)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XVI: SERVICING OP AMP CIRCUITS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: SERVICING OP AMPS

   a. Information outline

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Semiconductor Devices. Benton Harbor, MI: Heath Co., 1975.

2. Leonard, Vincient F., Jr. Transistor Circuit Design. Heathkit Continuing Education. Benton Harbor, MI: Heath Co., 1983.

3. Oleksy, Jerome E. Electronic Troubleshooting. Indianapolis, IN: Bobbs-Merrill Educational Publishing, 1983.

4. Schuler, Charles A. Electronics: Principles and Applications. 2nd ed. St. Louis: McGraw-Hill, 1984.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Review op amp information presented in Unit X.

B. Suggested supplemental material

1. Operational Amplifiers (E-87-332, video). Sedalia, MO: The Media Center, State Fair Community College, 1987. (Available for purchase from SFCC; available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

2. Mims, Forrest M. III. Engineer's Mini-Notebook: Op Amps. Fort Worth, Texas: Radio Shack, a division of Tandy Corp., 1986.

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XVI: SERVICING OP AMP CIRCUITS

LESSON 1: SERVICING OP AMPS

I. Terms and definitions

  A. Buffer--circuit that provides electrical isolation or high impedance from one circuit to another

  B. Common mode--signals that are identical with respect to amplitude and phase

  C. Dual-voltage power supply (or dual-polarity power supply)--refers to a power supply that produces a negative and a positive output with a common ground

  D. Mixer--in audio, a circuit that combines two or more input signals and produces a single output

  E. Nulled--condition of balance on a circuit that produces an output of 0V

  F. Op amp (operational amplifier)--high gain DC amplifier using negative feedback to determine gain of the amplifier stage. This linear amplifier is capable of amplifying in several different modes. Proper selection of feedback and input components allow the amplifier to add, subtract, average, integrate and differentiate inputs. (The term op is derived from the many "operations" this I.C. can perform.)

II. Op amp basics

  A. Construction

    1. Operational amplifiers (op amps) are direct coupled amplifiers with exceptionally high gain.

    2. Op amps were made in discrete form until the late 1960s when they were available in I.C. form.

    3. Op amps have a differential amplifier at the input stage.

    4. Stages after the differential amplifier provide increased gain.

    5. One of the inputs to the differential amplifier is called the inverting input and is represented by the minus sign.

    6. The other input is referred to as the non-inverting input and is represented by the plus sign.

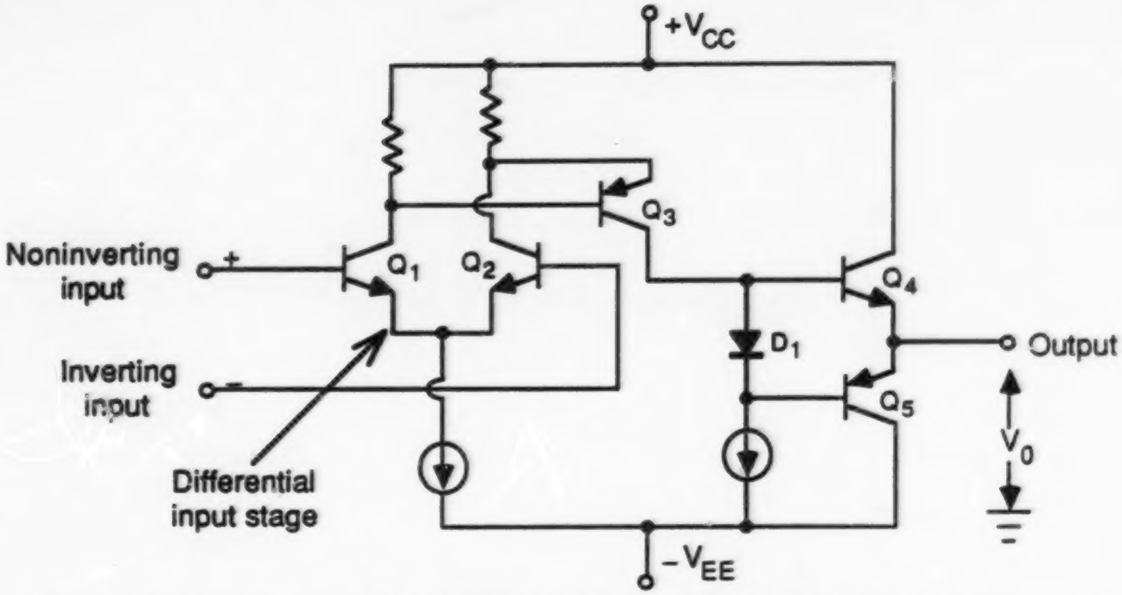
    7. If the two input voltages are equal, the output will be 0V.

    8. The output is said to be nulled if this condition exists.

    9. Once output is nulled, an applied input signal will cause the output to swing positive and negative, along with the input signal.

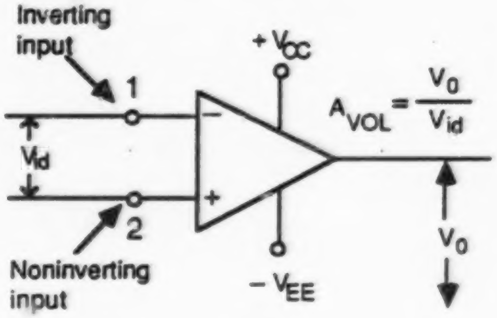
    10. The phase relationship between the input and output signal is dependent on which input the signal was applied to.

    11. If the input signal is applied to the inverting input, the output will be 180° out of phase with the input.


+V_CC
Noninverting input
+
Q1
Q2
Q3
Q4
D1
Q5
Output
Inverting input
−
Differential input stage
V0
−V_EE

Credit: Oleksy, Jerome E. Electronic Troubleshooting. Indianapolis, IN: Bobbs-Merrill Educational Publishing, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

Typical op amp


Inverting input
1
+V_CC
−
+
A_VOL = V0 / Vid
Vid
2
Noninverting input
−V_EE
V0

Credit: Electronic Troubleshooting, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

12. If the input signal is applied to the non-inverting input, no phase difference exists.

13. Op amps require a dual-voltage power supply.

B. Op amp characteristics

1. The following characteristics make the op amp desirable for many applications.

    a. High gain

    b. High input impedance

    c. Low output impedance

    d. Good low-frequency response

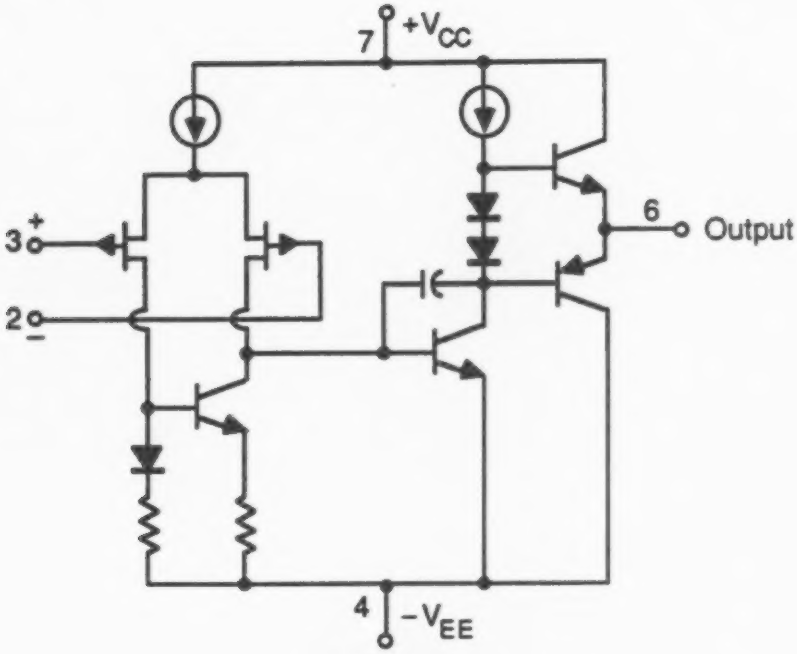
    e. Common mode rejection

    f. Low cost

2. BIFET op amps use FETs at the differential amplifier for even higher input impedance.

III. Op amp circuits

A. Open-loop gain



BIFET op amp

Credit: Electronic Troubleshooting, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

1. Op amps without feedback are in what is referred to as open-loop gain configuration.

2. Open-loop gain provides no degenerative feedback, so the amplifier utilizes all of the gain available from the op amp.

3. These op amps have extremely high gain--several thousand to over a million.

4. Op amps in open-loop configuration can be used as comparators to compare two signals placed at the inputs.

5. If the difference between the two inputs is zero, the output will be 0V.

6. Since the op amp has such a high gain in this configuration, the slightest difference in input voltage can be detected.

B. Inverting amplifier

1. An op amp in the inverting configuration will have the input signal applied to the inverting input, and the non-inverting input connects to ground either directly or through a dropping resistor.

2. Output is coupled through feedback resistor RF from output to inverting input.

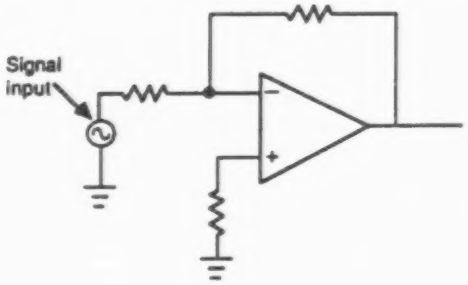
3. The feedback resistor (RF) couples the output signal, which is 180° out of phase, with the input back to the inverting input lead.

4. This negative feedback signal almost cancels out the input signal. Only a small amount of signal input is detectable. The input terminal is said to be at virtual ground since it is almost completely cancelled out.

5. This explains why the technician using an oscilloscope will see no signal (or very little) at this input.

6. The gain of the inverting configuration can be calculated by using the formula below.

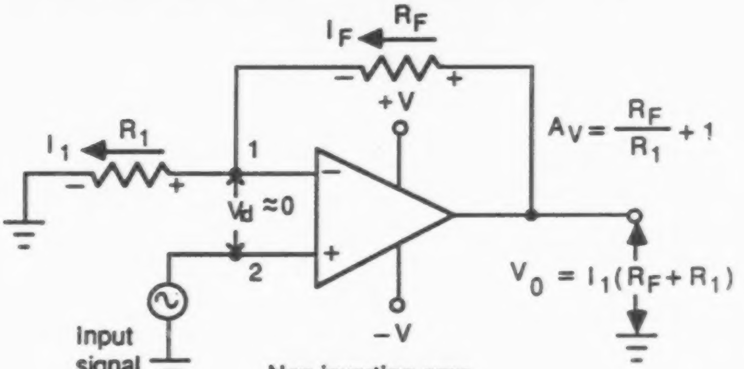
$$A = RF / R_{in}$$



Inverting amp

C. Non-inverting configuration

1. An op amp in this configuration will have the input signal applied to the non-inverting input, a feedback resistor connected from output to the inverting input, and a resistor from the inverting input to ground to form a voltage divider at this point.



Non-inverting amp

Credit: Electronic Troubleshooting, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

2. The output of this configuration is in phase with the input.

3. The output (0° phase difference) is fed back to the inverting input.

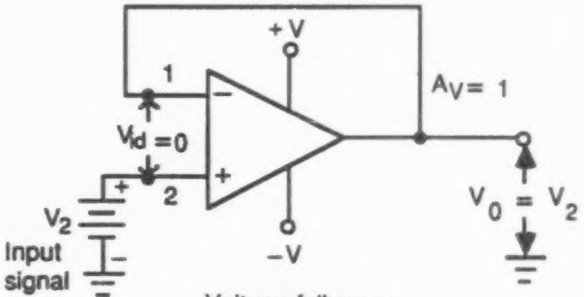
4. Since the output always amplifies the difference between the two input signals, gain is reduced and controlled by the value of RF.

5. Determine the gain of the non-inverting amplifier with this formula.

$$A = RF / R_{in} + 1$$

6. If output is connected directly back to input, gain is equal to 1.

7. This is called a voltage follower since there is no gain and output is in phase with input.



Voltage follower

Credit: Electronic Troubleshooting, 1983. Used by permission of Glencoe/McGraw-Hill Educational Division.

8. Voltage followers can be used when no gain is desired but the design requires a high impedance characteristic (buffering action).

9. Op amps, whether inverting or non-inverting, decrease in band width as gain is increased.

D. Differential mode

1. Op amps can be used as a difference amplifier to increase differential signals or compare two voltages.

2. If the two input voltages are equal, the output will be 0V.

3. If two common mode signals are applied to the input, the output is 0V.

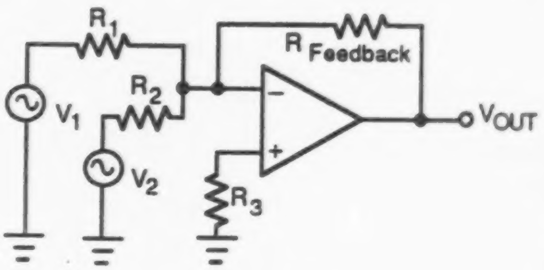
4. If a differential signal is applied to one input and common mode signals are applied to both inputs, only the differential output signal will appear at the output.

5. This configuration can be used to filter out undesired signals.

E. Mixers

1. Op amps can be used to mix AC signals.

2. Op amps can be used to add DC voltages.

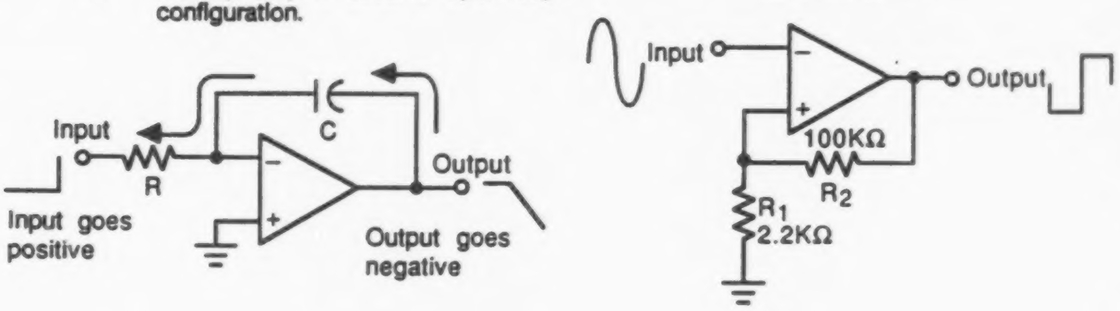


Summing amp

F. Wave-shaping circuits

1. Op amps can be used as Schmitt triggers to change a sine wave into a square wave.

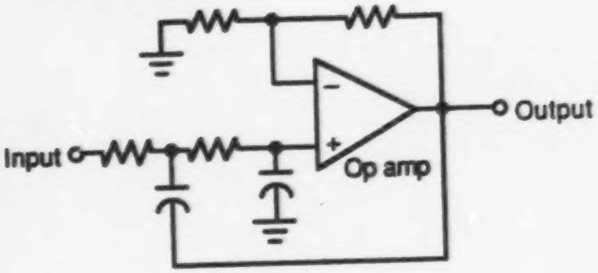
2. The op amp is used in open-loop configuration.

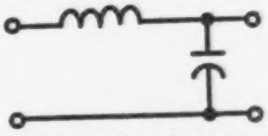


Op amps as integrators and Schmitt triggers

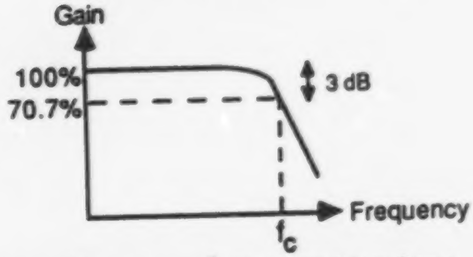
3. The op amp can also be used as an integrator to change a square wave into a ramp.

Low-pass filter


Output
Input
Op amp

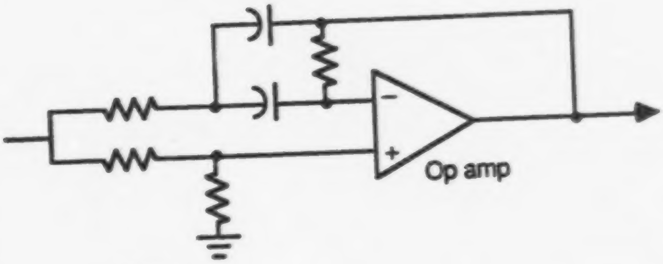


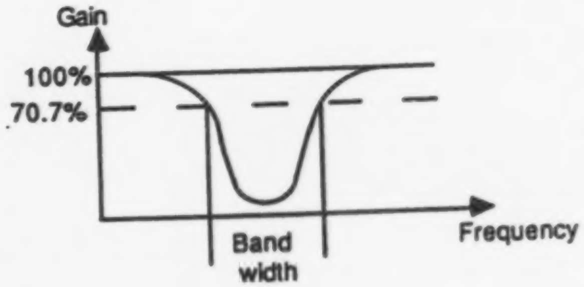
Simulated inductance



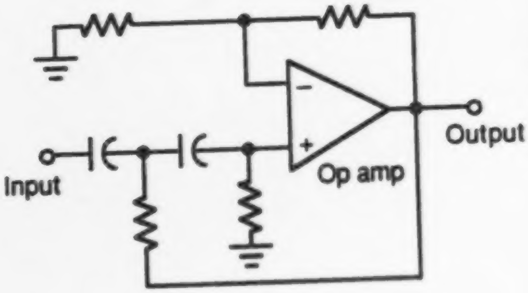
Cutoff frequency f_c is where the voltage gain drops to 70.7% of its maximum value

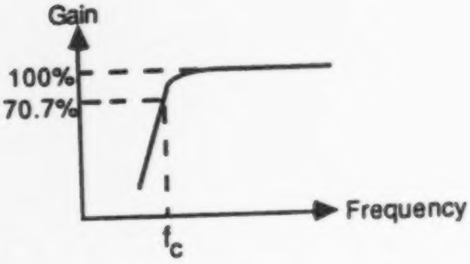
Band-stop (notch) filter



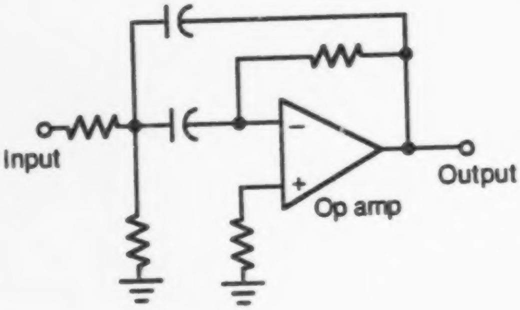


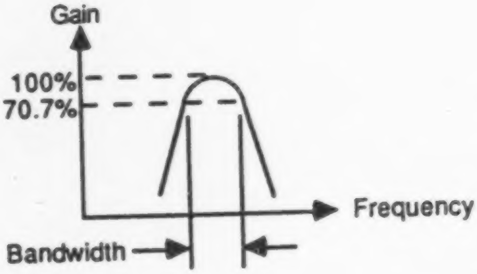
High-pass filter


Output
Input
Op amp



Band-pass filter


Input
Output
Op amp



G. **Active filters**

1. **Op amps are used in conjunction with resistors, inductors and capacitors to form low pass, high pass, bandpass and band-stop filters.**

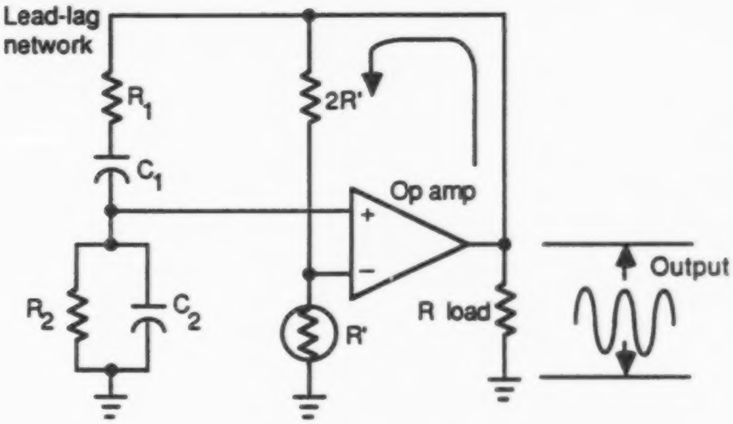
2. **The gain of the op amp makes the circuit active.**

3. **Very precise response curves can be achieved with active filters.**

H. **Oscillators**

1. **Since an oscillator is nothing more than an amplifier with positive feedback, the op amp can be used to create an oscillator.**

2. **A very popular oscillator made with op amps is the Wien-bridge oscillator.**



Wien-bridge oscillator

3. **The RC network at the inverting and non-inverting inputs create a lead-lag network to apply differential signals at the inputs of the op amp.**

IV. Troubleshooting op amp circuits

A. Circuit analysis

1. The technician should always use signal analysis first to isolate the faulty stage.

2. **When the faulty stage identified contains an op amp, the technician should first analyze the circuit to determine what the op amp does.**

3. **Since the op amp can be used for so many different applications, a technician must first determine what it does in that application.**

4. **There is no simple test that can be done with an ohmmeter to check an op amp. The best test is to substitute a known good op amp. If the circuit operates, the original op amp was defective.**

NOTE: Component analyzers can be purchased that compare the junctions of known good op amps with suspect op amps. These analyzers draw a signature of the known good component that can be compared with the suspect component.

B. Amplifiers

1. If the op amp is utilized as an amplifier, use an oscilloscope to observe input and output signals.
2. Remember that since the input is kept at virtual ground, it is necessary to probe before the input resistor to see an input signal.
3. If there is input and not output, the op amp is most likely faulty.
4. However, the op amp could possibly be ineffective due to loss of supply voltage or proper biasing.
5. In applications where the op amp is mixing input signals or voltages, there could be a complete loss of output or partial output.
6. If there is a complete loss of output, the most likely suspect is again the op amp itself or loss of supply voltage.
7. If partial loss of output seems to be the problem, the op amp and supply voltages are probably good. Suspect a faulty input resistor.

C. Open-loop mode

1. If the op amp is used as a comparator and 0V or null voltage is never achieved, the problem is most likely a defective op amp or dual voltage supply loss.
2. As always, be sure that both inputs are receiving input signals or voltages.
3. If the op amp is used as a Schmitt trigger, the most likely suspect is the op amp or loss of the dual voltage supply.
4. If the op amp is replaced, a null adjustment may be necessary.

   NOTE: This null adjustment can also be the source of the circuit failure.

D. Other circuits

1. In applications where the op amp is used as an integrator, check the following.
   a. Feedback capacitor
   b. Supply voltage
   c. Op amp
2. For oscillator applications, check the following.
   a. Phase shift components
   b. Supply voltage
   c. Op amp
3. For active filter applications, check the following.
   a. Feedback components

        - b. Input components
        - c. Supply voltage
        - d. Op amp

E. Cause of failure

    1. Although the cause of a component failure can't always be determined, some common reasons that op amps fail may help the technician prevent future problems.

    2. A few reasons op amps fail are listed below.

        - a. Excessive heat
        - b. Supply voltage too high (constant high or surge)
        - c. Input signal swing too large
        - d. Output short circuit (excessive loading)

MODULE: SEMICONDUCTOR DEVICES AND APPLICATIONS

UNIT XVI: SERVICING OP AMP CIRCUITS

UNIT TEST

Select "a" for true statements and "b" for false ones.

____ 1. Op amps have poor low-frequency response.

____ 2. Op amps generally require a dual-voltage power supply.

____ 3. Op amps are usually placed in closed-loop mode when connected as comparators.

____ 4. When the difference voltage applied to the inputs of a comparator is 0V, the output voltage is maximum.

____ 5. Op amps can be tested with an ohmmeter.

____ 6. If the technician monitors a large signal at the inverting input of an op amp, the op amp stage is faulty.

Select the option which answers the question or completes the statement.

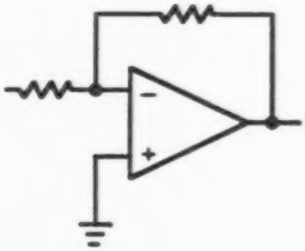
____ 7. Which describes common mode signals?

- a. Common ground
- b. Same phase
- c. Same amplitude
- d. Same amplitude and phase
- e. None of the above

____ 8. Which of the following is not a characteristic of op amps?

- a. High gain at any frequency
- b. High input impedance
- c. Low output impedance
- d. Good low-frequency response
- e. Low cost

____ 9. Identify the op amp circuit pictured.



- a. Adder
- b. Inverting amplifier
- c. Non-inverting amplifier
- d. Schmitt trigger
- e. Wien-bridge oscillator

____ 10. On an op amp used as an inverting amplifier, what should the technician expect to measure?

- a. Full supply voltage at the output
- b. 0V at the output
- c. Virtual ground at the input
- d. A very large signal at the input
- e. None of the above

____ 11. If the technician suspects an op amp is faulty, what should be done?

a. Substitute the I.C.
b. Test the I.C.
c. Measure supply voltages.
d. Remove and replace the I.C.
e. Measure output voltages.

____ 12. Which steps of procedures should a technician follow when servicing op amps?

a. Measure supply voltages, then monitor input and output signals.
b. Monitor input and output signals, then measure supply voltages.
c. Substitute op amp I.C.s.
d. Test the op amp and support components.
e. Place the op amp in an I.C. tester.

ANSWERS TO UNIT TEST (E6)

1. b
2. a
3. b
4. b
5. b
6. a
7. d
8. a
9. b
10. c
11. a
12. b